Appendix G

Vibration Technical Memo ***and Addendum***

King County

QSI DOCUMENT: QSI 2020-01
KING CO. CONTRACT: E00364E15

CEDAR HILLS REGIONAL LANDFILL 2020 SITE DEVELOPMENT PLAN ENVIRONMENTAL IMPACT STATEMENT

VIBRATION ANALYSIS TECHNICAL REPORT

Prepared for:

King County Solid Waste Division
201 S. Jackson Street, Suite 701
Seattle, WA 98104

Submitted by:

Herrera Environmental Consultants, Inc.
2200 6th Ave, Suite #1100
Seattle, WA 98121

August 27, 2020

DOCUMENT DISTRIBUTION

Document: Cedar Hills Regional Landfill 2020 Site Development Plan Environmental Impact Statement

Vibration Analysis Technical Report

QSI Document: QSI 2020-01

Original Issue Date: August 27, 2020

CERTIFICATION DOCUMENT

JRE DOCUMENT: QSI 2020-01

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415 SE 177th Ave
Unit 345
Vancouver, WA 98683

Greg Price

John Alberti

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1. Federal Transit Administration Report FTA-VA-90-1003-06, *Transit Noise and Vibration Impact Assessment*, May 2006
2. JR 336, *Noise and Vibration Study of Cedar Hills Regional Landfill North Flare Station,* J R Engineering, May 2014
3. *Revised Site Development Plan for Cedar Hills Regional Landfill,* Herrera, HDR, BHC, June 2016
4. King County*, Preliminary Draft Environmental Impact Statement,* TBR

1.0 INTRODUCTION

This report presents the results of the vibration analysis performed for the Cedar Hills Regional Landfill (CHRLF) 2020 Site Development Plan Environmental Impact Statement. The report describes the potential impacts on the surrounding community from worst case vibration scenarios under each of the Action Alternatives under consideration as well as the No Action Alternative. The Action Alternatives are described in detail in Reference 4.

The vibration assessment was based on new analysis that incorporate new buildings in the existing buffer and on previous vibration studies of the North Flare Station. Due to the large distance between the operational areas of the Alternatives and the nearest properties, projected vibration levels at the property line are far below the levels required to cause human annoyance and even further below the level required to cause structural damage. None of the Action Alternatives under consideration create a significant impact relative to the No Action Alternative. No vibration mitigation would be necessary

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QSI DOCUMENT: QSI 2021-01
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King County Solid Waste Division
201 S. Jackson Street, Suite 701
Seattle, WA 98104

Submitted by:

Herrera Environmental Consultants, Inc.
2200 6th Ave, Suite #1100
Seattle, WA 98121

December 3, 2021

415 SE 177th Ave., #345 / Vancouver, WA 98683
Phone (425) 337-9472
Fax (425) 337-9578

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4. King County, *Preliminary Draft Environmental Impact Statement*, TBR

1.0 INTRODUCTION

A vibration analysis was performed for the Cedar Hills Regional Landfill (CHRLF) Draft EIS that evaluated projected vibration levels from continued landfill operation for a range of proposed alternatives [Ref. 2]. The analysis was primarily based on typical vibration levels of common construction equipment that would likely be operating in support of daily landfill operation and construction activities. The vibration data and criteria for impact and building damage was taken from the Federal Transit Authority's noise and vibration impact assessment guidelines for transit projects [Ref. 1].

Comments on the DEIS were that there was no measurement of in-use equipment at the site and that the projected noise levels were not validated with measurements. This memo presents the results of vibration measurements taken at the landfill in August 2021 and further validates that the expected vibration levels that will be experienced by the community are minimal and are below the FTA threshold for noticeability.

Of the equipment currently operated or proposed for future use at the landfill, the vibratory roller used to compact gravel and soil is the strongest expected source of vibrations. A series of measurements were performed to evaluate the vibration characteristics of the roller and confirm the propagation characteristics through the soil at the landfill. Further, the vibration levels observed with the roller inoperative demonstrate that the level of vibration associated with typical landfill operations – primarily the tipping of trailers, use of bulldozers, and compactors in the "active area" of the landfill, would continue to be insignificant.

The evaluation is intended to evaluate the vibration levels through the local ground. Individual buildings will likely react differently to the ground vibration levels based on their construction and weight. Evaluation of specific building responses is beyond the scope of these measurements and analysis.

2.0 VIBRATION MONITORING PROTOCOL

The Hamm H14i is the roller currently used at CHRLF. Nominal specifications for the roller are:

- Weight: 30,175 lb.
- Engine: 154 horsepower 4 cylinder manufactured by Deutz.
- Vibration Characteristics:
  - Mode I – Frequency 30 Hz, Amplitude 0.076 in.
  - Mode II – Frequency 36 Hz., Amplitude 0.035 in.

Vibration measurements were taken with the H14i operating in two areas:

- On top of Area 5 and near the western edge of the upper plateau. This area received waste until 2005 and an intermediate cover placed in 2007.
- In Area 8, the current active area, at an elevation that was relatively level with the existing grade.

When the roller was in Area 5, measurements were taken for each vibration setting at a distance of approximately 50 feet from the roller and at a location on the western property line as shown in Figure 2.1. Vibration measurements were taken at the property line with the roller OFF as well.

For roller operation in Area 8, measurements were taken at a distance of 50 feet from the roller, 408 feet from the roller, and again at the same location on the western property line.

The vibration measurements were made while the vibrating roller was moving. Nominally, about 2 minutes of data was acquired for each condition. This was enough time for the roller to perform two forward and two backward passes past the accelerometer.

<u>FIGURE 2.1: VIBRATION MONITORING LAYOUT</u>

For each measurement, a 3-axis accelerometer was magnetically mounted to a 14-inch long section of angle iron that was driven approximately 12 inches into the ground. The accelerometer was mounted to the 2 inches remaining above ground level. The stakes for Positions 1-3 were driven in approximately 2 weeks prior to the vibration monitoring. The stake at position 4 could not be mounted in advance due to the area being active and was located on the day of the measurements.

- The x-axis was oriented towards the source and shows the longitudinal vibrations
- The y-axis was oriented parallel to the ground and perpendicular to the x-axis and provides the lateral vibration level.

- The z-axis was oriented perpendicular to the ground for vertical vibration level.

The calibration data for the accelerometer was provided by The Modal Shop, from whom the accelerometer was rented. The accelerometer was a PCB Model 356M98 high sensitivity accelerometer, Serial Number 27219.

Each measurement was recorded using a Bruel & Kjaer front end with the Bruel & Kjaer BK Connect software run on a laptop PC. The recorded data was post processed using the software which performed the integration from the acceleration (measured directly by the sensor) to get velocity. Velocity is the primary metric used for building damage criteria as well as human response to vibration.

The data was filtered using a 7 Hz High Pass filter to remove low frequency self noise in the sensor.

Sections of the recordings where there was interference of one kind or another was not used in the analysis. Examples of interference observed in the recorded data included vehicles passing by, aircraft, truck driver CB interference picked up by the accelerometer cable, and other instantaneous spikes in the level that were likely due to grass or leaves blowing against the mounting stake or the portions of the cable near the accelerometer.

The overall vibration velocity magnitude was calculated by taking the square root of the sum of the squares of each component vibration level from each axis. From this, a 1-second RMS average velocity amplitude was computed. The raw output from the software was in m/s and m/s^2, which were converted to in/s and in/s^2 for comparison with the criteria discussed in Section 3.0. The vibration velocity, in terms of decibels, was computed as

$$L_v = 20 \cdot log\left(\frac{v_{RMS}}{v_{ref}}\right)$$

Throughout this report v_{ref} is one micro inch per second (1×10^{-6} in/sec). To avoid confusion with noise decibels, the notation VdB is used throughout for vibration decibels.

3.0 VIBRATION IMPACT CRITERIA

3.1.1 Human Perception / Annoyance Criteria

The FTA has established guidelines for vibration impact criteria based on a building's use and the frequency with which vibration causing events occur. These are summarized in Table 3.2**.** Since there are no known Category 1 (high sensitivity use buildings)[1] in the vicinity, the Category 2 land use category (for residences) is the most applicable vibration criterion for analysis of the CHRLF Alternatives. Landfill operations are generally continuous throughout the day and the "frequent event" impact criteria is the most appropriate criteria. For Category 2 frequent events, the criterion for vibration impacts is 72 VdB (see Table 3.2).

TABLE 3.1: EXPECTED RESPONSE TO VIBRATION

Vibration Velocity Level	Human Response
65 VdB	Approximate threshold of perception for many humans
75 VdB	Approximate dividing line between barely perceptible and distinctly perceptible. Many people find transit vibration at this level annoying.
85 VdB	Vibration tolerable only if there are an infrequent number of events per day.

TABLE 3.2: FTA VIBRATION IMPACT CRITERIA

Ground Borne Vibration Impact Criteria for General Assessment (VdB re 1 micro-inch/sec)			
Land Use Category	**Frequent Events**	**Occasional Events**	**Infrequent Events**
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB	65 VdB	65 VdB
Category 2:	72 VdB	75 VdB	80 VdB

[1] This category includes buildings where vibration levels, including those below the threshold of human annoyance, would interfere with operations within the building. Examples include buildings where vibration-sensitive research and manufacturing* is conducted, hospitals with vibration-sensitive equipment, and universities conducting physical research operations. The building's degree of sensitivity to vibration is dependent on the specific equipment that will be affected by the vibration. Equipment moderately sensitive to vibration, such as high resolution lithographic equipment, optical microscopes, and electron microscopes with vibration isolation systems are included in this category

Residences and buildings where people normally sleep.			
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB

Notes:

1. "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2. "Occasional Events" is defined as between 30 and 70 vibration events per day. Most commuter trunk lines have this many operations.
3. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4. Source: Reference 1.

3.1.2 Structural Damage Criteria

The FTA document also presents vibration levels that are the threshold values for causing structural damage to various categories of buildings; these limits are expressed in terms of the Peak Particle Velocity (PPV).

Because the degree of engineering used for buildings in the community surrounding CHRLF is not known, Building Category III (for non-engineered timber and masonry structures) was used as the criteria for the vibration damage analysis. The PPV threshold criteria for Building Category III is 0.2 in./sec.

TABLE 3.3: VIBRATION DAMAGE CRITERIA[2]

Building Category	PPV (in/sec)	Approximate L_V (VdB)
I. Reinforced-concrete, steel, or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage[3]	0.12	90
RMS velocity in decibels (VdB) re 1 micro-inch/sec		

[2] From Reference 1
[3] Fragile historical buildings are an example.

4.0 RESULTS

4.1 Summary

A summary of the RMS vibration levels and the peak particle velocity (PPV) is provided in Table 4.1.

TABLE 4.1: VIBRATION LEVEL SUMMARY

Roller Position	Roller Mode (2, 3)	Sensor Position (Ref Figure 2.1)	Sensor Distance (ft)	RMS Vibration Velocity (VdB, re 1e-6 in/s)	PPV (in/s)
Area 5	Mode I	1	50	102.75	0.221
Area 5	Mode II	1	50	100.56	0.158
Area 5	Mode II	2	2100	45.83	0.001
Area 5	Mode I	2	2100	44.96	0.000
Area 5	OFF	2	2100	49.10 (1)	0.002
Area 8	Mode II	3	50	87.78	0.040
Area 8	Mode I	3	50	93.21	0.083
Area 8	Mode II	4	408	54.39	0.003
Area 8	Mode I	4	408	56.09	0.003
Area 8	Mode I	2	1700	45.92	0.001
Area 8	OFF	4	408	50.53	0.001

Notes:

1. Maximum RMS level occurred during a small aircraft flyby. Excluding this event, the maximum measured vibration level with the roller OFF would have been about 46.7 VdB. Since the roller OFF condition has higher measured vibration levels than the roller ON condition, the conclusion is that the operation of the roller had no meaningful influence.
2. Mode I: 30 Hz, 0.076 inch amplitude (nominal values)
3. Mode II: 36 HZ, 0.035 inch amplitude (nominal values)

At the western property line, the measured vibration levels are well below the typical threshold for human detection, let alone building damage. Measurements were not taken at night to observe the background vibration level.

The vibration data taken at 50 feet and 408 feet with the roller in Area 8 provide an opportunity to compare the projected vibration decrease with distance compared to the data provided in the FTA reference document. Analysis indicated that the RMS velocity decreased at a slightly higher rate than predicted by the FTA equation and the PPV decreased at about the same rate as predicted (±0.001 in/sec).

Table 4.2 presents distances below which vibrations could be noticeable (with 65 VdB being the threshold) or building damage (PPV ≥ 0.2 in/sec) is predicted to occur. The most conservative estimate for potential noticeability occurs with the roller operating on hard compacted soils at distance of 906 feet or less and in Mode I (30 Hz vibration). The most conservative estimated distance for building damage is 53.4 feet which is also for the roller in Mode I on hard soil.

TABLE 4.2: ESTIMATED DISTANCES FOR NOTICEABILITY AND BUILDING DAMAGE

Soft Soil Analysis								
	Lvref (VdB)	Distance (ft)	Ref Dist (ft)	Projected Lv (VdB)		Distance (ft)	PPVref (in/sec)	Projected PPV (in/sec)
Mode II	96.81	287.3	25	65.00		17.1	0.113	0.200
Mode I	102.24	435.8	25	65.00		27.8	0.235	0.200
Hard Soil Analysis								
	Lvref	D	Ref Dist	Projected Lv (VdB)		D	PPVref	Projected PPV (in/sec)
Mode II	109.59	766.1	25	65.00		42.7	0.447	0.200
Mode I	111.78	906.3	25	65.00		53.4	0.625	0.200

Note that the distances computed in Table 4.2 use the equations presented in the FTA reference document even though the test data indicated that the roll off of the rms velocity (in VdB) for soft soils may decrease at a higher rate than those equations predict.

If operation of the roller on known hard ground is anticipated within 1000 feet of the property line, it may be advisable to conduct vibration monitoring to determine if noticeable vibration levels are observed at the property line. As indicated in Table 4.2 a roller would have to be within 55 feet before the projected vibration level reaches the criteria for building damage.

4.2 Area 5 Results

The following figures present the vibration results with the roller operating in Area 5. Observations about the measurements are:

- The roller is supposed to nominally vibrate at 30 or 36 Hz. For operations in Area 5, we noted that the primary frequencies were about 28.5 Hz and 37.5 Hz. There were tones at half these frequencies – the reason is not clear, but it could be from a reflective, hard layer close to the surface.
- The RMS Vibration level is about 102 VdB at about 50 feet and the PPV is about 0.221 in/s. When adjusted to the 25-foot reference distance used by FTA, these increase to about Lvref = 112 VdB and the computed PPV ref is about 0.625 in/s.
- In spite of the fact that the measured equipment levels are stronger than predicted by the FTA guidebook, the observed levels at the property line are well below the normal threshold for detectability.
- The PPV at the property line was much less than the criteria for building damage.

FIGURE 4.1: VIBRATION TIME HISTORY - AREA 5, DISTANCE = 50 FEET, OPERATING MODE I

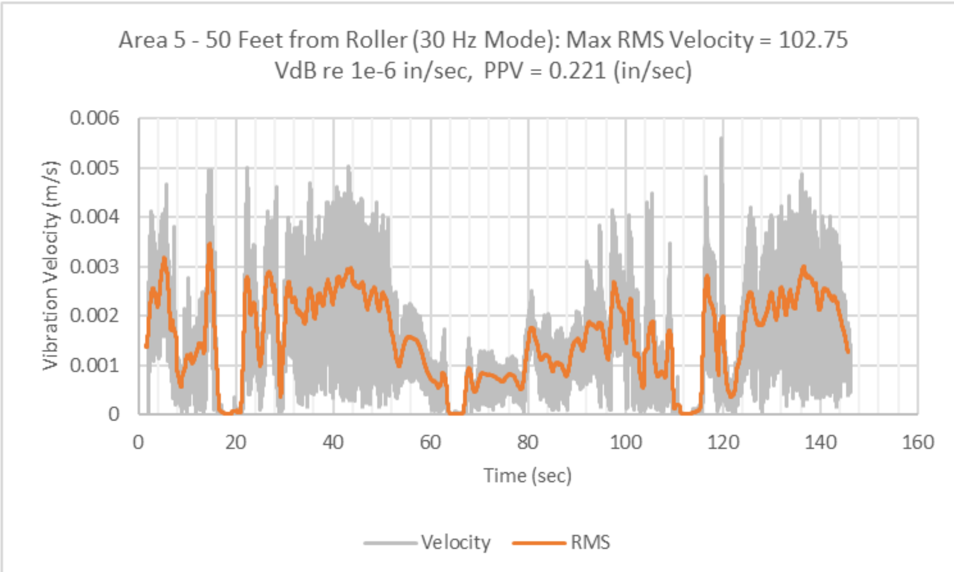


FIGURE 4.2: VIBRATION SPECTRAL TIME HISTORY - AREA 5, DISTANCE = 50 FEET, OPERATING MODE I

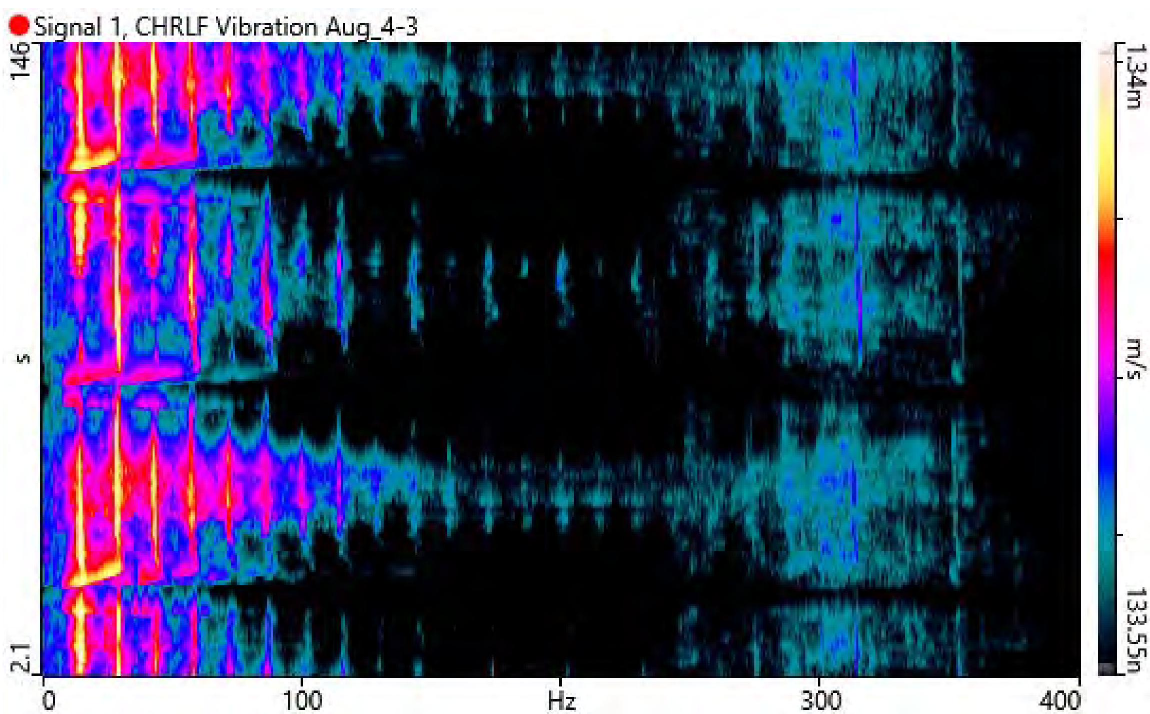


FIGURE 4.3: VIBRATION TIME HISTORY - AREA 5, DISTANCE = 50 FEET, OPERATING MODE II

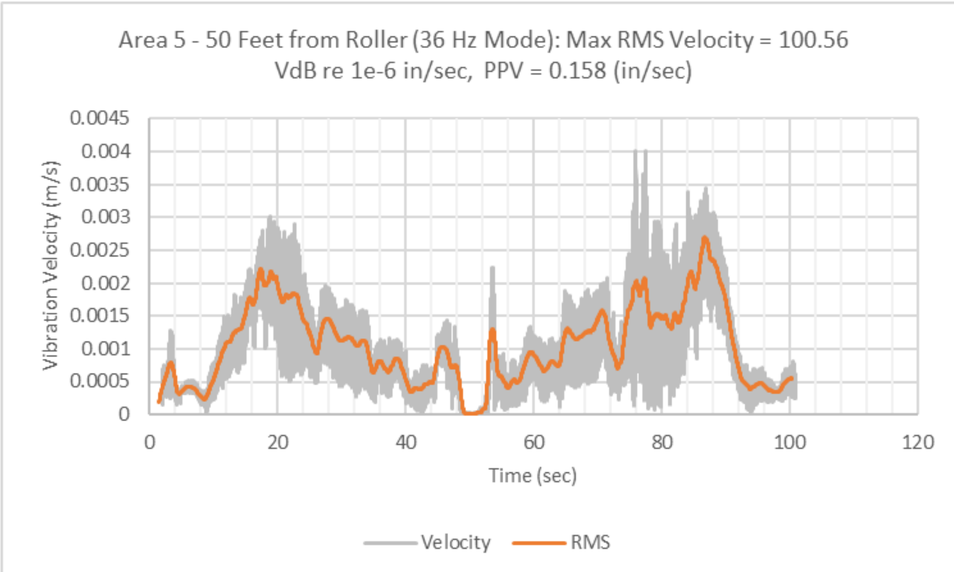
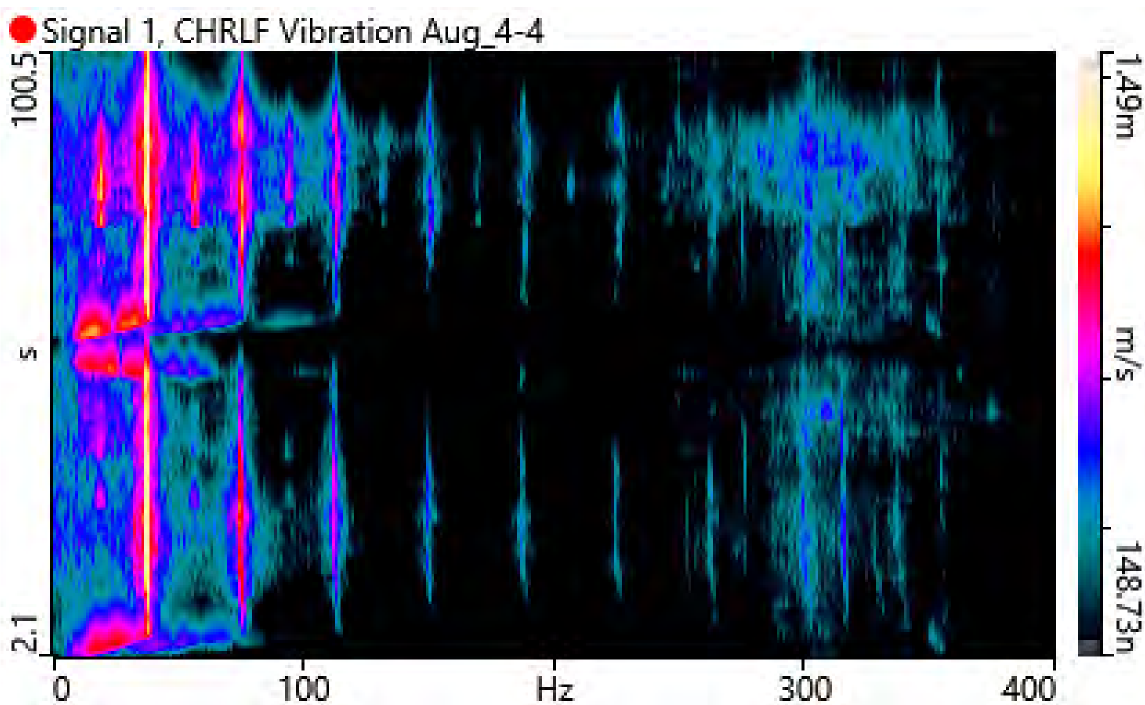
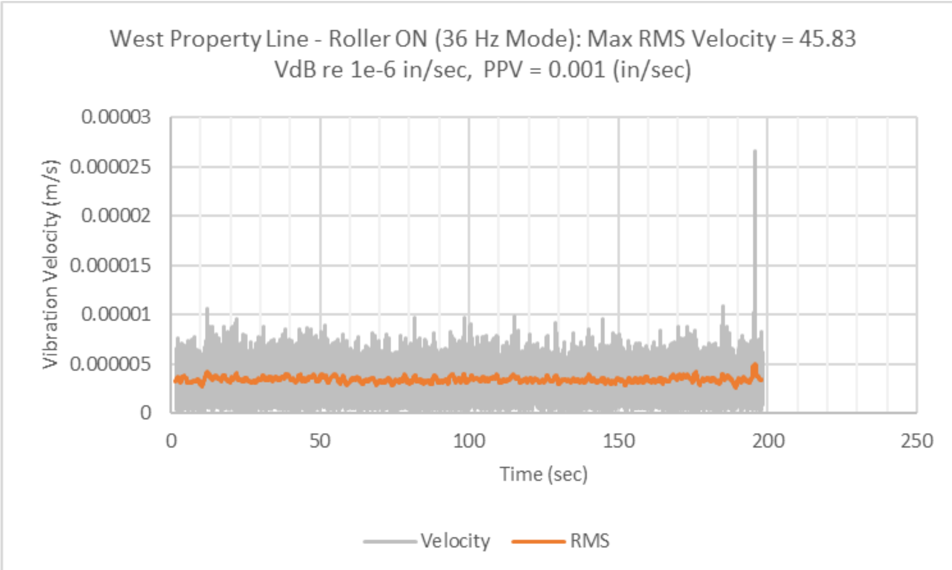


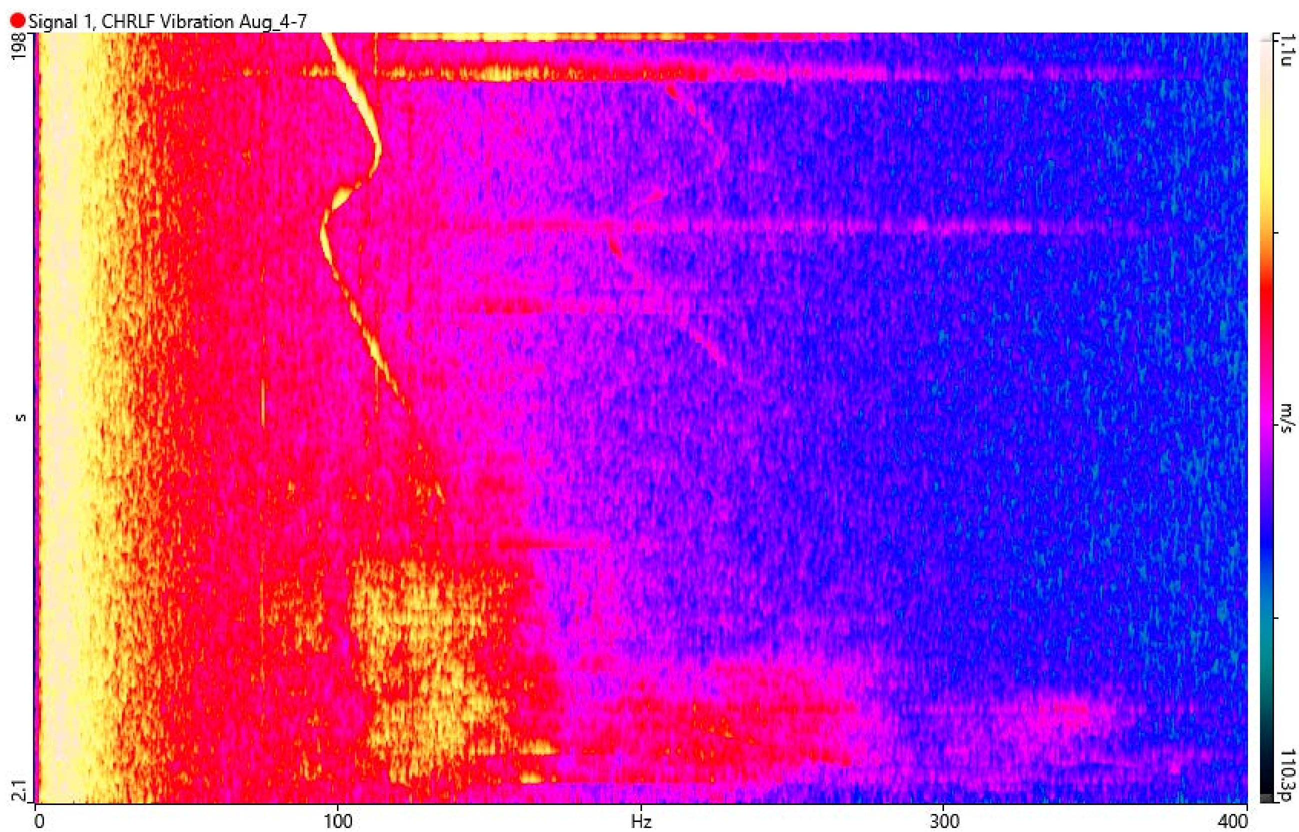
FIGURE 4.4: VIBRATION SPECTRAL TIME HISTORY - AREA 5, DISTANCE = 50 FEET, OPERATING MODE II



<u>FIGURE 4.5: VIBRATION TIME HISTORY – WEST PROP LINE, ROLLER IN AREA 5, DISTANCE = 2100 FEET, OPERATING MODE II</u>

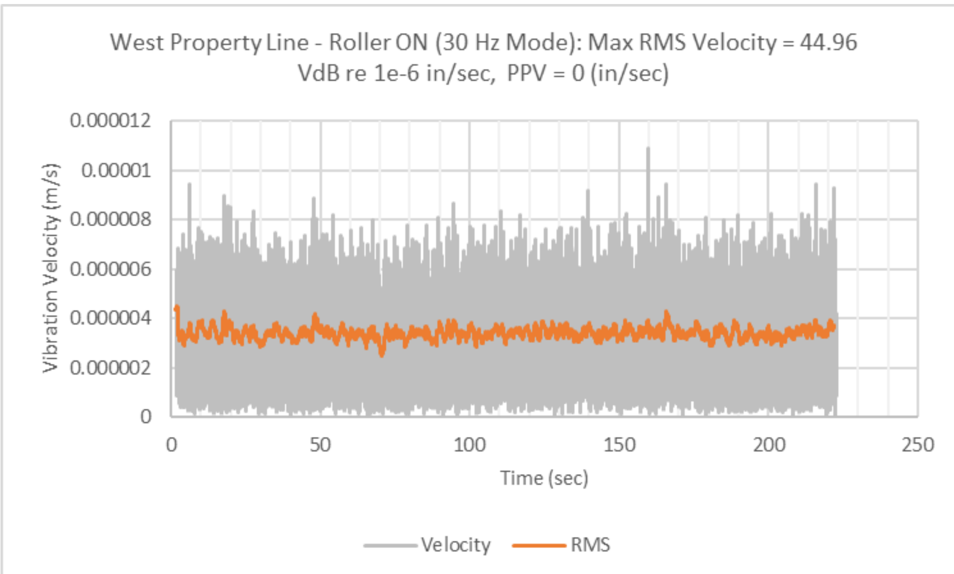


<u>FIGURE 4.6: VIBRATION SPECTRAL TIME HISTORY – WEST PROP LINE, ROLLER IN AREA 5, DISTANCE = 2100 FEET, OPERATING MODE II</u>

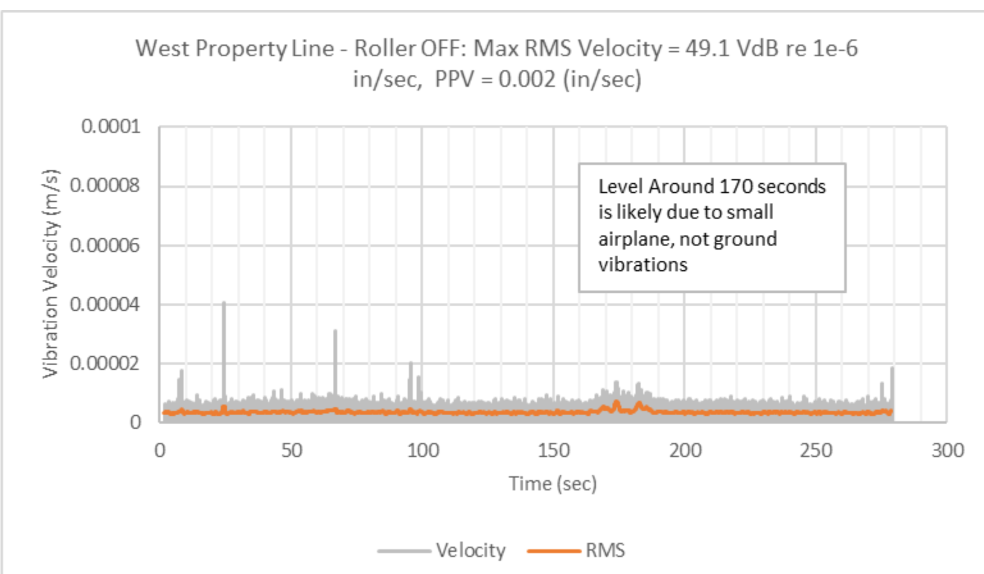


Review of Figure 4.6 shows that there <u>may</u> be a weak vibration at about 75 Hz (2^{nd} harmonic of the nominal 36 Hz primary frequency) at the west property line that might be associated with the roller in Area 5. However, the level, whether associated with the roller or some other activity, is far below the threshold for human observation and no other expected vibration tones are observed, so this conclusion cannot be confirmed from this test data.

<u>FIGURE 4.7: VIBRATION TIME HISTORY – WEST PROP LINE, ROLLER IN AREA 5, DISTANCE = 2100 FEET, OPERATING MODE I</u>



<u>FIGURE 4.8: VIBRATION TIME HISTORY – WEST PROP LINE, ROLLER OFF</u>

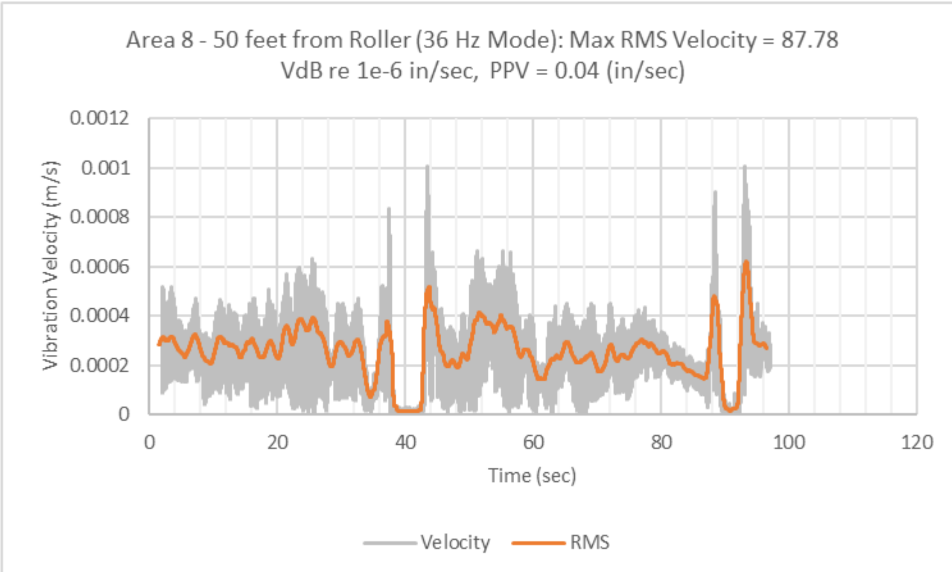


There is no significant difference at the western property line between the roller ON and OFF vibration levels. The maximum level RMS level in Figure 4.8 is caused by a small plane passing by. Discounting this period of time, the maximum RMS level would be about 46.7 VdB, so the results would be similar to the conditions when the roller was operating.

4.3 Area 8 Results

- With the roller in Area 8, the vibration levels at 50 feet from the unit are significantly lower than when in Area 5. This is probably due to the ground being less compacted and less rocky than in Area 5.
- At a distance of about 408 feet, the levels had diminished below the 65 VdB threshold for being noticeable.
- At the western property line, the vibration levels were well below (about 20 dB below) the level for detectability (by a factor of about 10). Actual levels may be even lower as it is likely that this is near the background vibration levels.
- PPV levels were much less than the nominal criteria for building damage.

<u>FIGURE 4.9: VIBRATION TIME HISTORY - AREA 8, DISTANCE = 50 FEET, OPERATING MODE II</u>



<u>FIGURE 4.10: VIBRATION SPECTRAL TIME HISTORY - AREA 8, DISTANCE = 50 FEET, OPERATING MODE II</u>

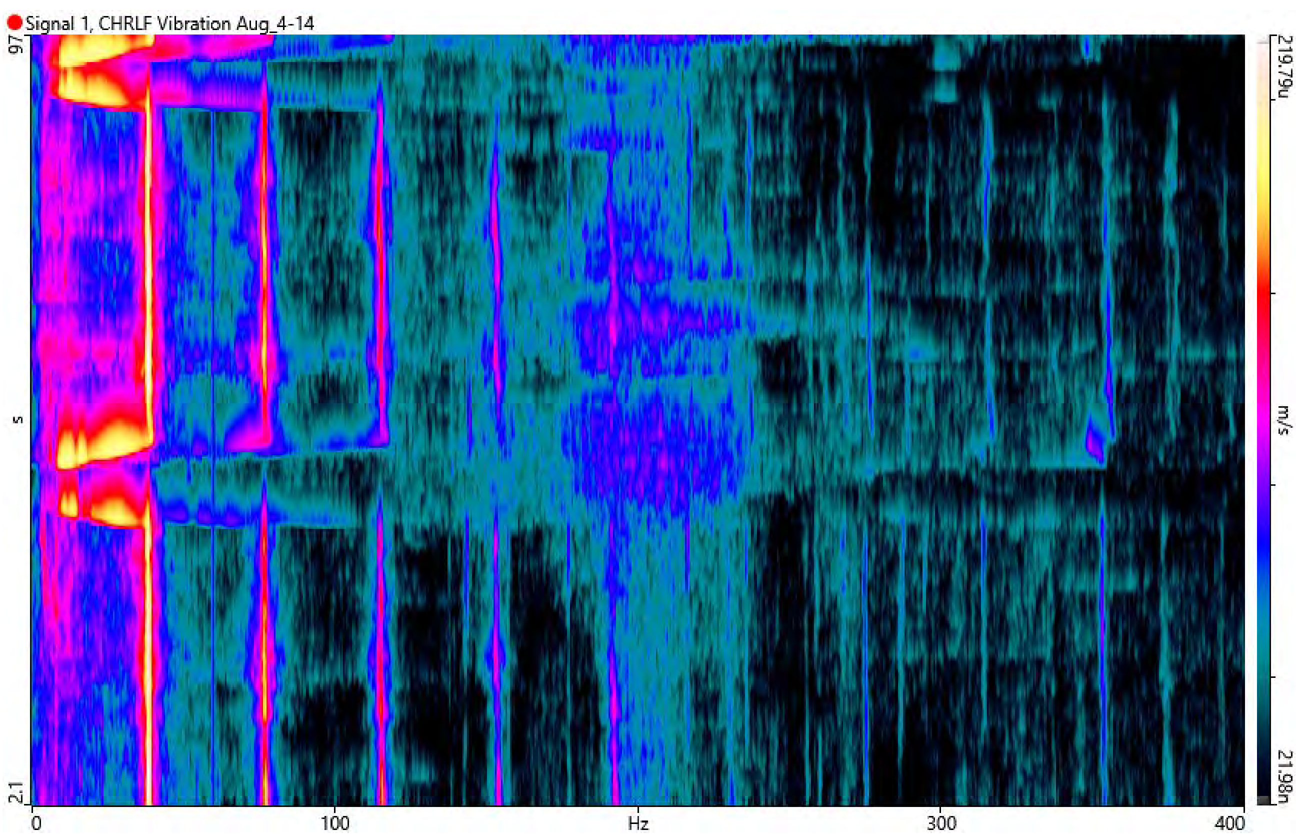


FIGURE 4.11: VIBRATION TIME HISTORY - AREA 8, DISTANCE = 50 FEET, OPERATING MODE I

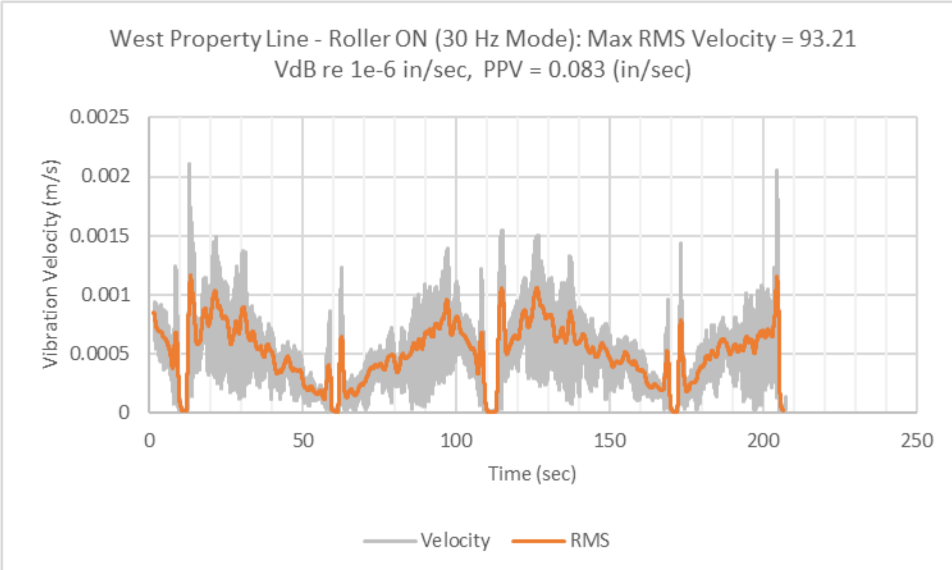


FIGURE 4.12: VIBRATION SPECTRAL TIME HISTORY - AREA 8, DISTANCE = 50 FEET, OPERATING MODE I

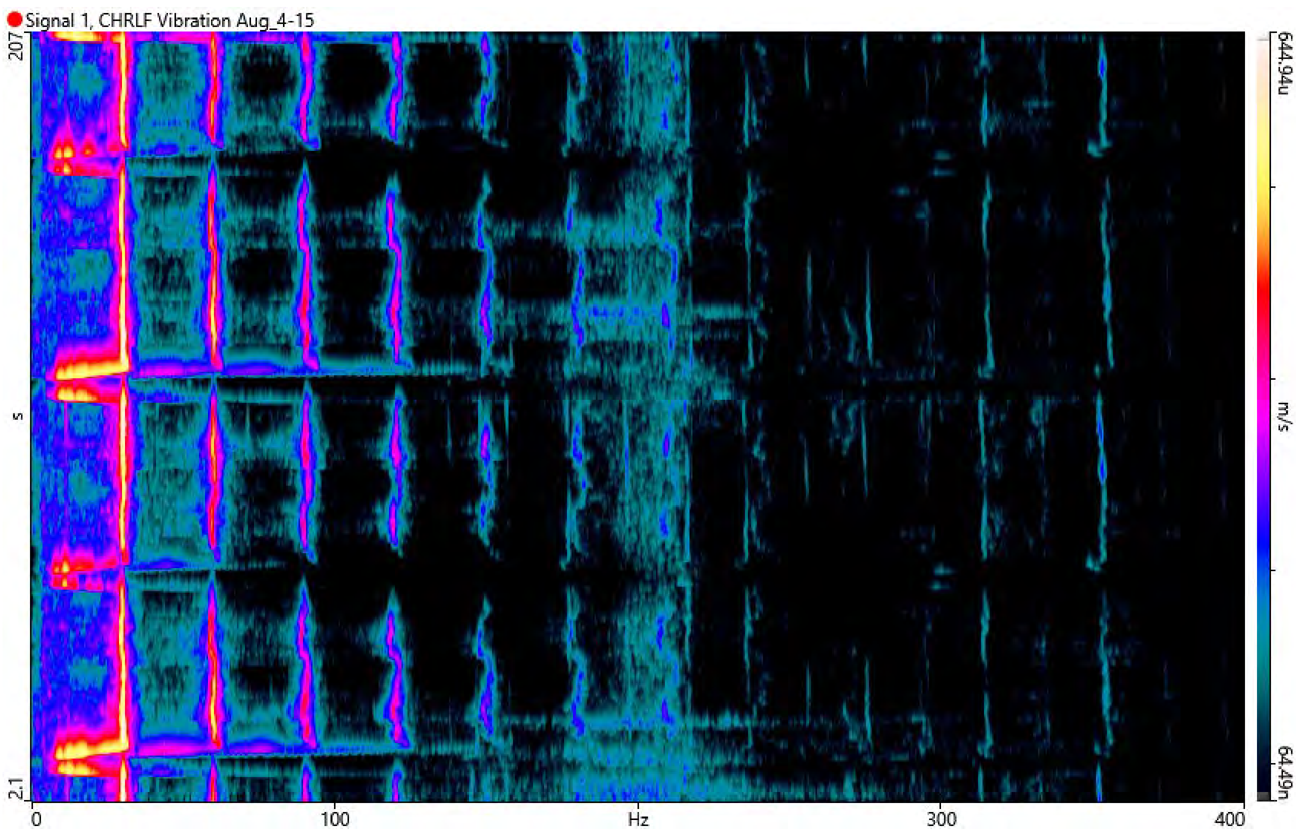


FIGURE 4.13: VIBRATION TIME HISTORY - AREA 8, DISTANCE = 408 FEET, OPERATING MODE II

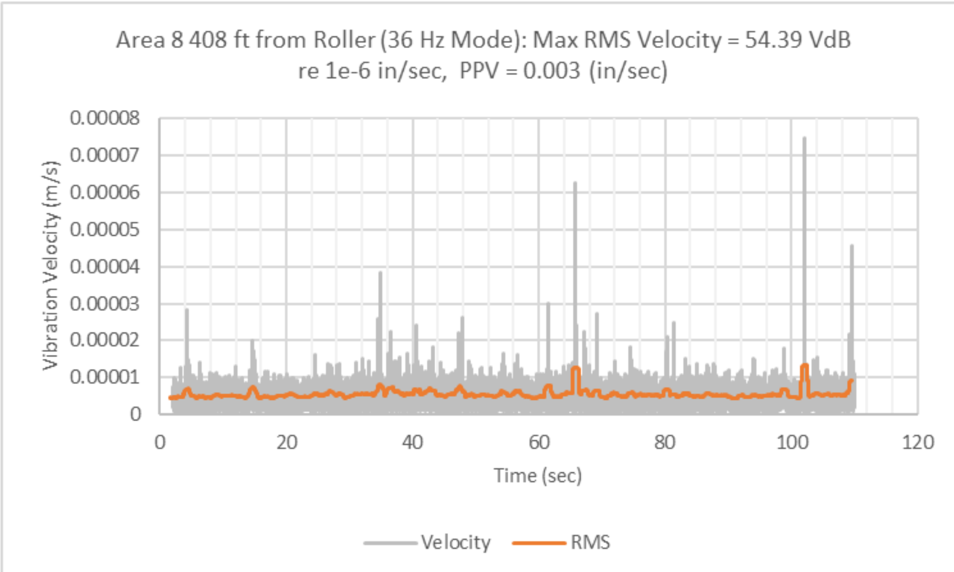


FIGURE 4.14: VIBRATION SPECTRAL TIME HISTORY - AREA 8, DISTANCE = 408 FEET, OPERATING MODE II

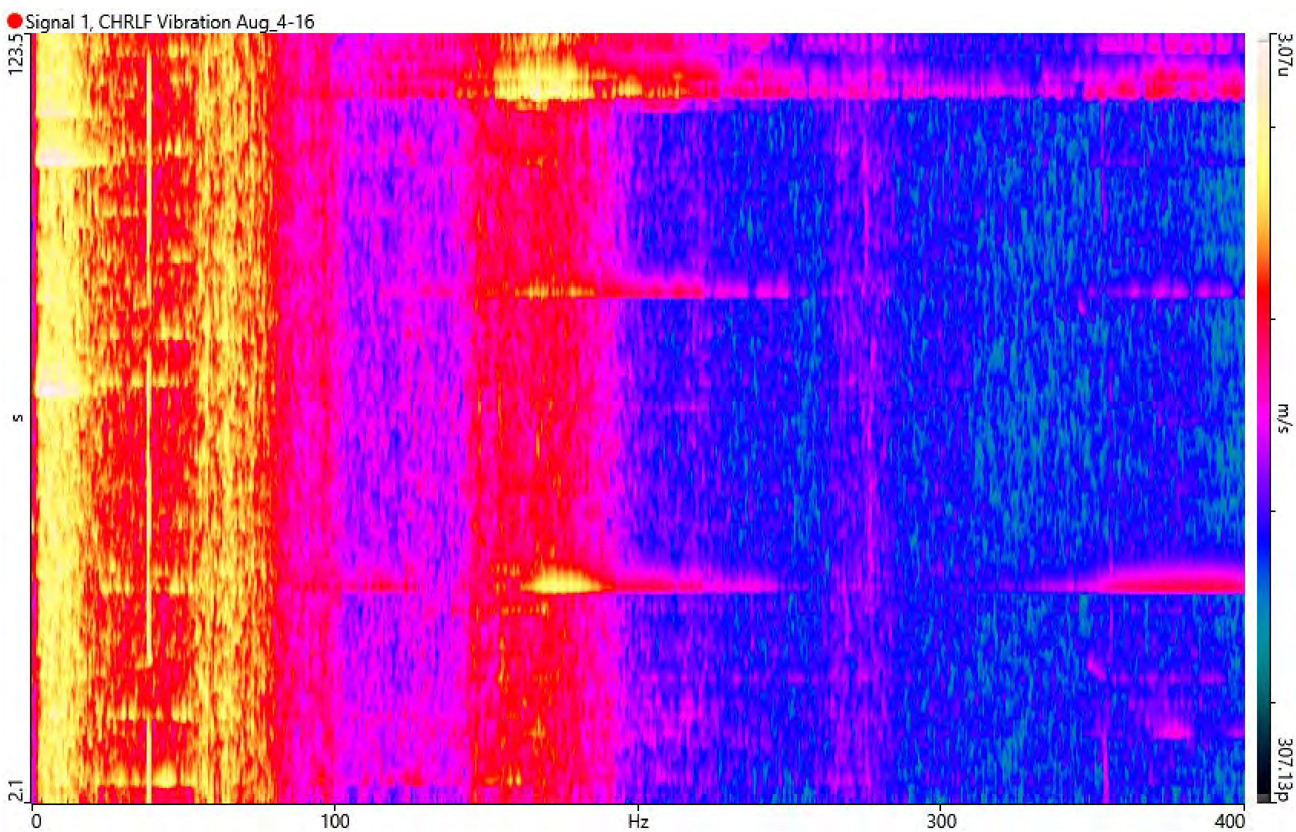


FIGURE 4.15: VIBRATION TIME HISTORY - AREA 8, DISTANCE = 408 FEET, OPERATING MODE I

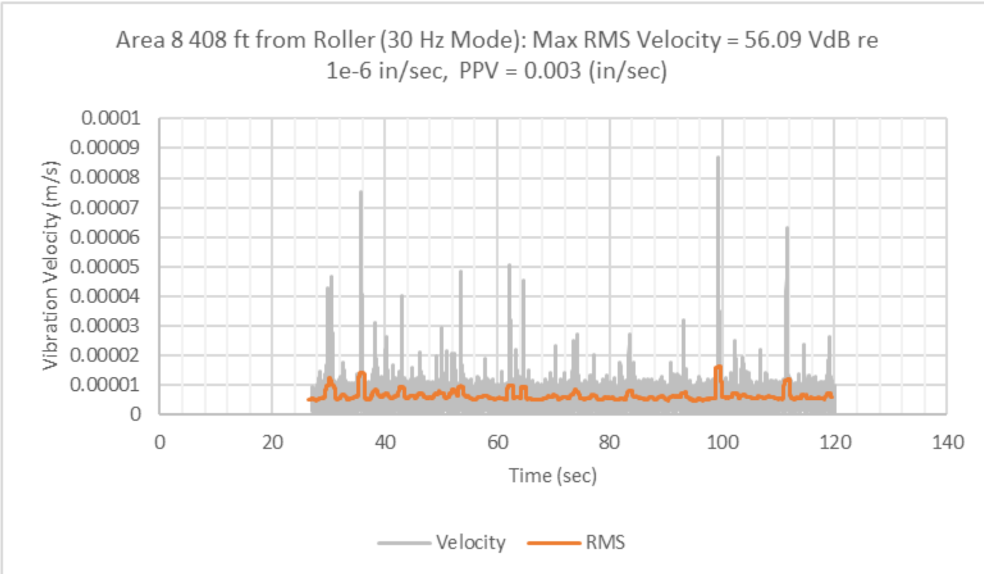


FIGURE 4.16: VIBRATION SPECTRAL TIME HISTORY - AREA 8, DISTANCE = 408 FEET, OPERATING MODE I

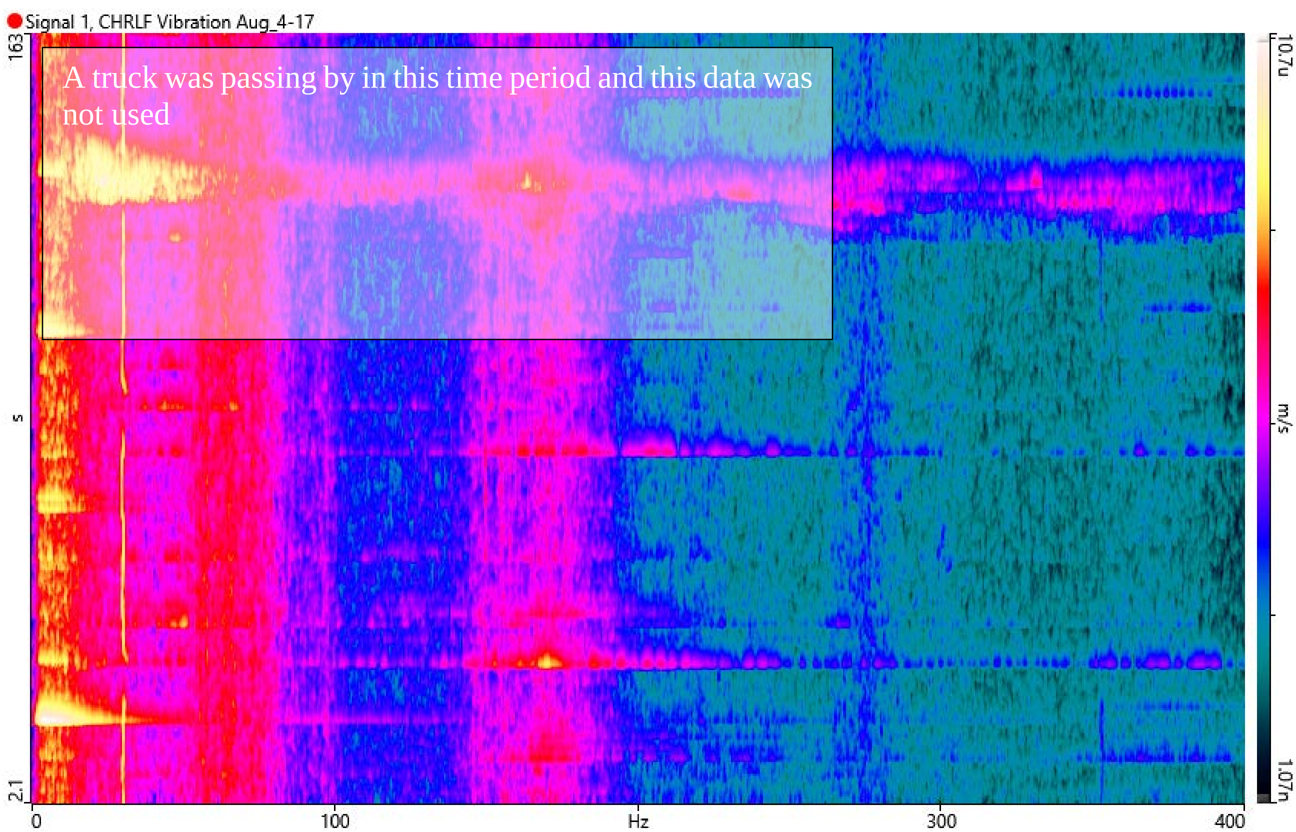


FIGURE 4.17: VIBRATION TIME HISTORY - AREA 8, DISTANCE = 1700 FEET, OPERATING MODE I

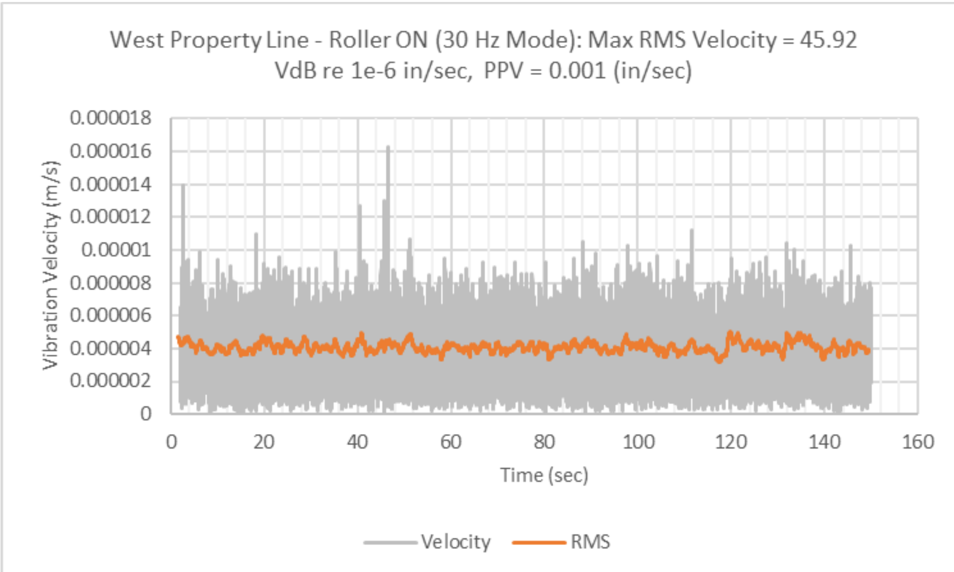


FIGURE 4.18: VIBRATION SPECTRAL TIME HISTORY - AREA 8, DISTANCE = 1700 FEET, OPERATING MODE I

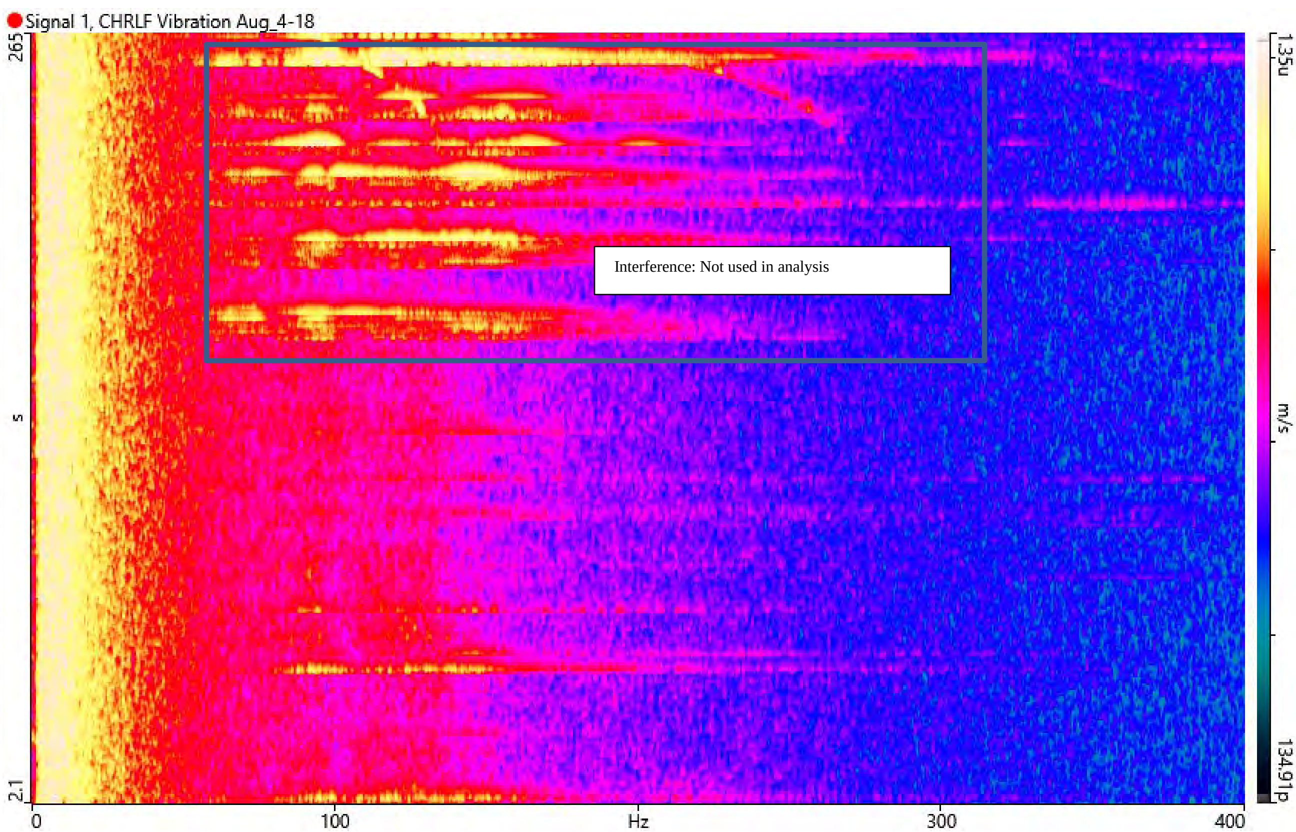
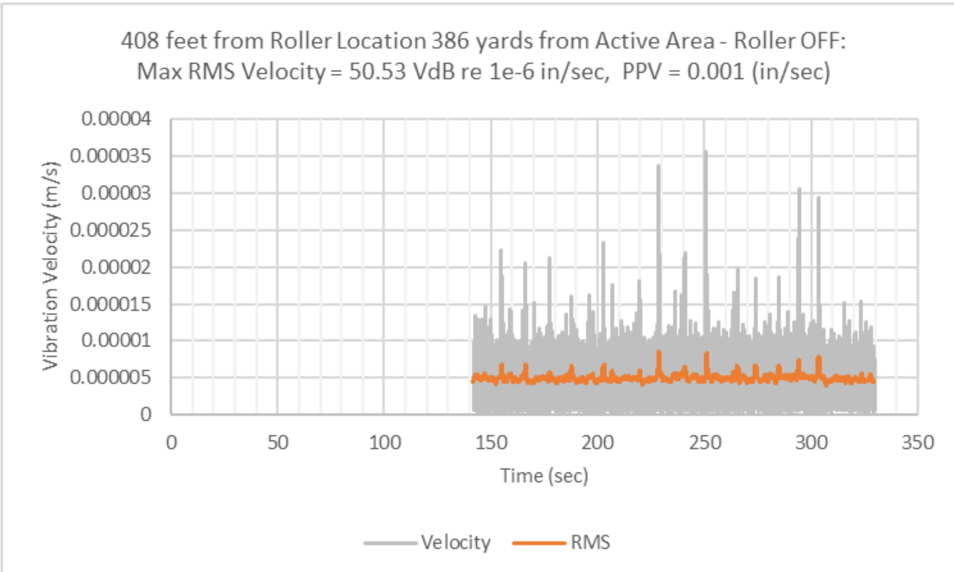


FIGURE 4.19: VIBRATION TIME HISTORY – WEST HAUL RD LOCATION, ROLLER OFF (ONLY ACTIVE AREA OPERATING)



2.0 DEFINITIONS AND ACRONYMS

CHRLF: Cedar Hills Regional Landfill

FTA: Federal Transit Administration

JRE: J R Engineering

KCC: King County Code

LV: The RMS Vibration Velocity expressed in decibels (VdB) re 1 micro-inch/second.

NFS: North Flare Station

Peak Particle Velocity (PPV): The peak signal value of an oscillating vibration velocity waveform. Throughout this document, PPV is expressed in inches per second.

QSI: Quietly Superior, Inc.

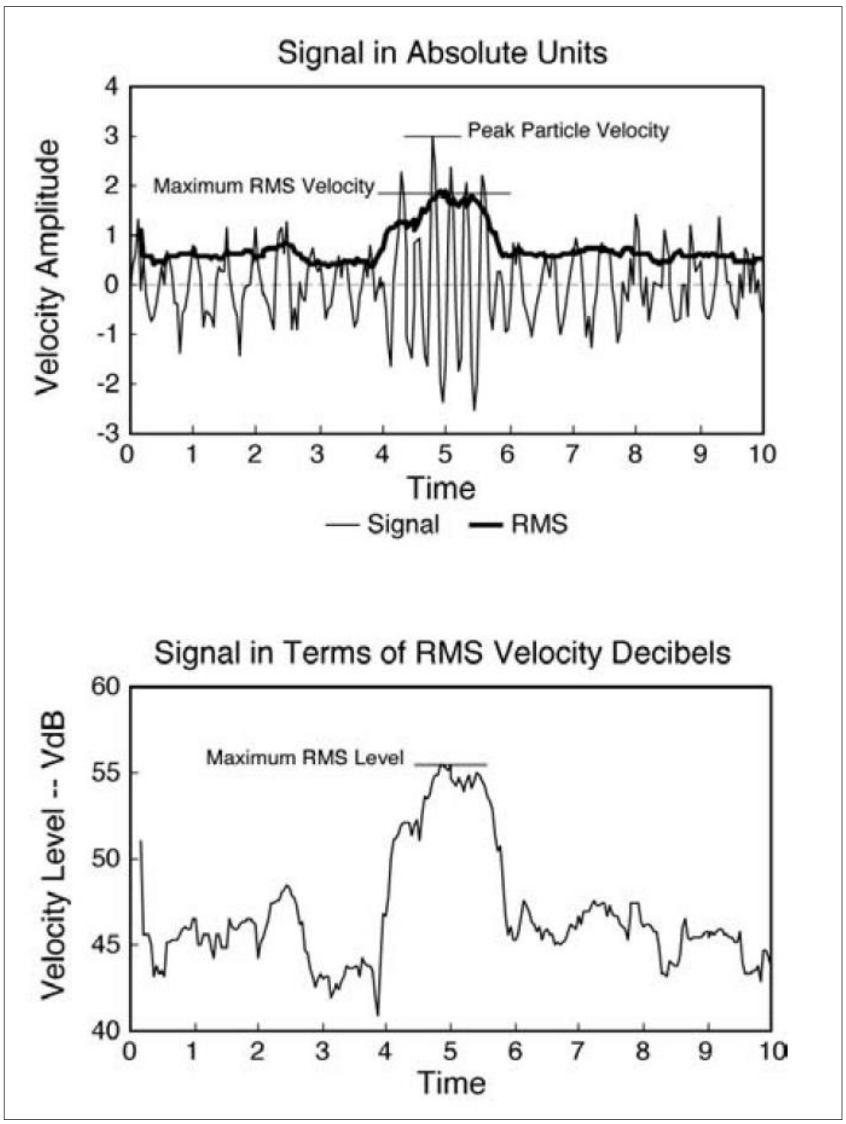
RMS Velocity: The square root of average velocity squared, usually over a 1 second time period.

3.0 VIBRATION ANALYSIS

3.1 Vibration Concepts

Vibration is an oscillatory, back and forth, motion which results in zero net displacement (over time) of a medium (gas, liquid, or solid). Vibration can be described in terms displacement, velocity, or acceleration. Human and structural responses to vibration are most closely aligned with vibration velocity and acceleration and most documentation specifies human response criteria and damage criteria in terms of vibration velocity.

FIGURE 3.1: DIFFERENT METHODS OF DESCRIBING A VIBRATION SIGNAL[1]



[1] From Reference 1

Figure 3.1 shows several ways in which fluctuating vibration velocity can be described. In the top diagram, the thin line shows the instantaneous velocity with time; net velocity is zero. The Peak Particle Velocity (PPV) is simply the maximum instantaneous velocity. Because the average net velocity is zero, it is generally more convenient to describe the intensity of the time averaged signal in terms of the Root Mean Square (RMS) velocity – this is the square root of the average velocity squared over a specified time interval, usually one second. RMS velocity is shown as the thicker line in the upper diagram. RMS velocity is always positive. Because of the large variation in vibration signals, the RMS velocity is usually expressed using decibels (similar to acoustics). The vibration velocity level is 20 times the log of the RMS signal compared to a reference RMS value.

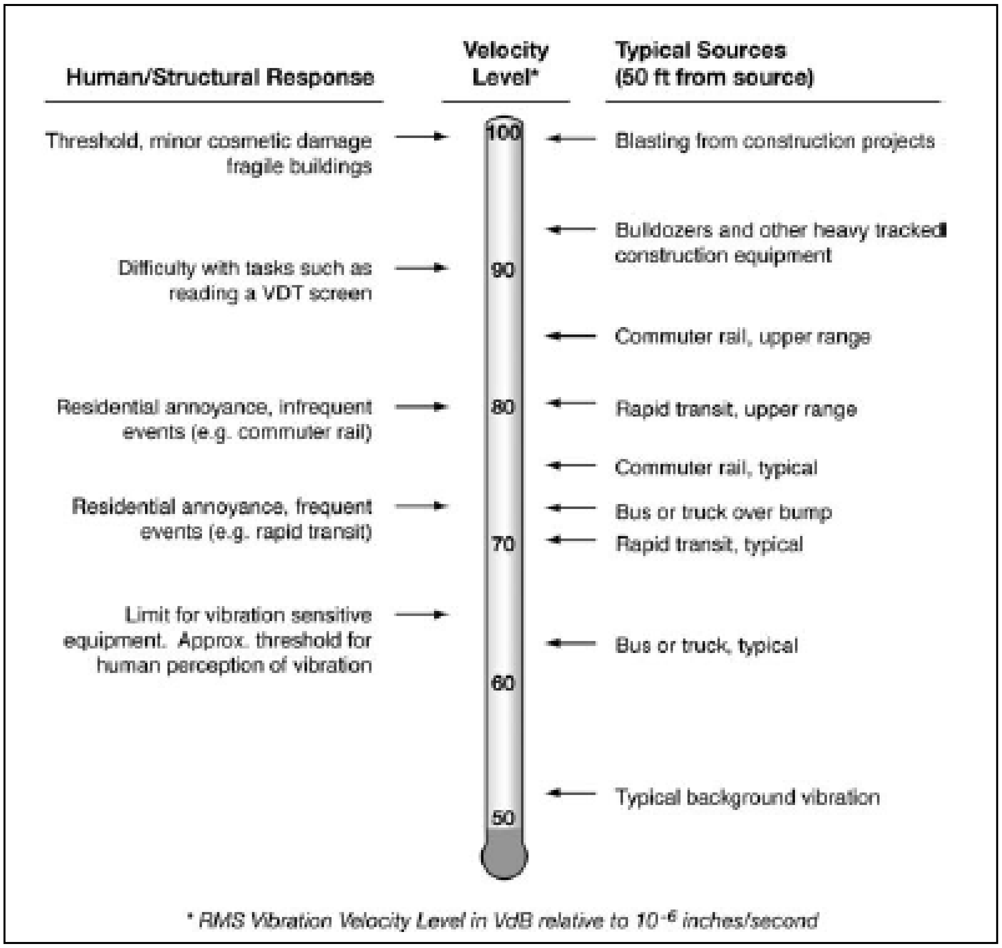
$$L_v = 20 \cdot log\left(\frac{v}{v_{ref}}\right)$$

Throughout this report v_{ref} is one micro inch per second (1×10^{-6} in/sec). To avoid confusion with noise decibels, the notation VdB is used throughout for vibration decibels.

There is no governing regulatory standard for acceptable vibration levels, federally or in King County Code (KCC). The Federal Transit Administration (FTA) Report, *Transit Noise and Vibration Impact Assessment* [Reference 1] notes that there is relatively little data regarding human response to general vibration. However, the FTA report presents criteria that have been developed based on human response to frequent or infrequent vibrations from rail traffic. Since the CHRLF vibration sources are generally in continuous operation, vibration levels associated with the landfill are compared against the FTA criteria for frequent vibration causing events.

Figure 3.2 shows typical levels of vibration for a range of sources and subjective responses to those particular vibration levels.

FIGURE 3.2: TYPICAL LEVELS OF GROUND-BORNE VIBRATION[2]



[2] From Reference 1

3.2 Site Description

The properties on the North, East, and West sides of CHRLF are generally residential in nature. Maple Hills Elementary School is located about 1,800 feet west of the landfill property line. The property on the southern border is an industrial composting facility (Cedar Grove Composting) that is not a vibration sensitive receptor. A commercial Christmas tree farm operates off the northeast corner of the CHRLF property.

There are no known uses, within a reasonable distance, that would be particularly sensitive to vibration such as vibration-sensitive manufacturing and research, university research labs, or vibration sensitive research at hospitals.

The landfill has a 1,000-foot buffer zone around the perimeter of the property that keeps vibration generating equipment away from the community. Under Options 1 and 2 for each of the three Action Alternatives under consideration, some landfill support facilities will be built within the existing 1000-foot buffer but would maintain an approximately 500-foot or greater distance to the property lines. No refuse would be placed in the 1000-foot buffer. Construction and landfilling operations would not occur within the 1000-foot buffer zone, except during construction of the Options 1 and 2 landfill support facilities. Under Option 3, the main landfill support facilities would be relocated to a site in Renton, and some facilities would be relocated on-site at CHRLF but not in the buffer.

3.3 Vibration Impact Criteria

3.3.1 Human Perception / Annoyance Criteria

The FTA has established guidelines for vibration impact criteria based on a building's use and the frequency with which vibration causing events occur. These are summarized in Table 3.1. Since there are no high sensitivity use buildings in the vicinity, the Category 2 land use category (for residences) is the most applicable vibration criterion for analysis of the CHRLF Alternatives. Landfill operations are generally continuous throughout the day and the "frequent event" impact criteria is the most appropriate criteria. For Category 2 frequent events, the criterion for vibration impacts is 72 VdB.

TABLE 3.1: GROUND BORNE VIBRATION IMPACT CRITERIA[3]

Ground Borne Vibration Impact Criteria for General Assessment (VdB re 1 micro-inch/sec)			
Land Use Category	**Frequent Events**	**Occasional Events**	**Infrequent Events**
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB	65 VdB	65 VdB
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB

Notes:

1. "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2. "Occasional Events" is defined as between 30 and 70 vibration events per day. Most commuter trunk lines have this many operations.
3. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.

[3] Reference 1.

3.3.2 Structural Damage Criteria

The FTA document also presents vibration levels that are the threshold values for causing structural damage to various categories of buildings; these limits are expressed in terms of the Peak Particle Velocity (PPV).

Because the degree of engineering used for buildings in the community surrounding CHRLF is not known, Building Category III (for non-engineered timber and masonry structures) was used as the criteria for the vibration damage analysis. The PPV threshold criteria for Building Category III is 0.2 in./sec.

TABLE 3.2: VIBRATION DAMAGE CRITERIA[4]

Building Category	PPV (in/sec)	Approximate L_V (VdB)
I. Reinforced-concrete, steel, or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90
RMS velocity in decibels (VdB) re 1 micro-inch/sec		

3.4 Projected Vibration Levels

3.4.1 Heavy Equipment Vibration Levels

The FTA report presents vibratory data for a variety of rail and construction equipment sources. These construction equipment levels are applicable to sources at CHRLF and are summarized in Table 3.3. The expected vibration sources to be operating at the landfill are bulldozers (large and small), loaded trucks, and, potentially, vibratory rollers that may be used in road construction near the edges of the buffer zone. When moving, excavators on site would create maximum vibration levels similar to the large or small bulldozer.

No pile driving is anticipated for any of the Alternatives or the No Action Alternative.

Vibration levels were conservatively calculated by using the highest vibration causing source, the vibratory roller, and by assuming that it was operating on the landfill buffer line or at the extents of the proposed landfill support facilities developments, whichever was closer to the property boundary.

[4] From Reference 1

TABLE 3.3: SOURCE VIBRATION LEVELS[5]

Table 12-2. Vibration Source Levels for Construction Equipment (From measured data.[7,8,9,10])

Equipment		PPV at 25 ft (in/sec)	Approximate L_v† at 25 ft
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (sonic)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory Roller		0.210	94
Hoe Ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

† RMS velocity in decibels (VdB) re 1 micro-inch/second

[5] Reference 1

The projected vibration levels at the property line from the equipment operating at the CHRLF are shown in Table 3.4. Vibration levels, in terms of both PPV and Lv, are presented for heavy equipment operating on the 1000-ft buffer line and the approximate 500-ft distance between proposed buildings and the property line.

In each case the projected vibration level is:

- Below the 0.2 PPV threshold for Category III building damage.
- Below the 72 VdB threshold for human annoyance.
- Below the 65 VdB threshold for human perception.

TABLE 3.4: PROJECTED VIBRATION LEVELS AT PROPERTY LINE

	Source Vibration Levels				Projected Vibration Level		
Equipment	PPV	Lv	Source Distance		Receiver Distance	PPV	Lv
	(in/sec)	(VdB)	(ft)		(ft)	(in/sec)	(VdB)
Large Bulldozer	0.089	87	25		1000	0.000	38.9
Small Bulldozer	0.003	58	25		1000	0.000	9.9
Loaded Trucks	0.076	86	25		1000	0.000	37.9
Vibratory Roller	0.210	94	25		1000	0.001	45.9
Large Bulldozer	0.089	87	25		500	0.001	48.0
Small Bulldozer	0.003	58	25		500	0.000	19.0
Loaded Trucks	0.076	86	25		500	0.001	47.0
Vibratory Roller	0.210	94	25		500	0.002	55.0

The conclusion is that the proposed Alternatives and Options will not create an impact to the community. Projected vibration levels at the property line would remain below the threshold for noticeability for all Action Alternatives. Since they would not be noticeable, there is no change compared to the No Action Alternative.

To further support this finding, Figures 3.3 to 3.6 graphically show the outermost contours of the vibration levels that could cause damage, annoyance, or be noticeable assuming that vibration generating equipment is on the landfill buffer line. Each contour is well within the CHRLF property line. Under the vast majority of circumstances, equipment would be further from the buffer line, so normal operational vibration contours would generally be closer to the center of the landfill than those shown in the figures.

FIGURE 3.3: HEAVY EQUIPMENT VIBRATION CONTOURS - NO ACTION ALTERNATIVE AND ALTERNATIVES 1-2 WITH OPTION 3

FIGURE 3.4: HEAVY EQUIPMENT VIBRATION CONTOURS - ALTERNATIVES 1 -2 WITH OPTIONS 1 -2

Alternative 3 has the same basic maximum vibration contours as Alternatives 1 and 2, but the northeast corner reflects the landfilling operations that would occur in that quadrant. Also, the property line and buffer line adjustment that would occur when the King County owned property in the northeast is incorporated into the CHRLF property is apparent.

FIGURE 3.5: HEAVY EQUIPMENT VIBRATIONS - ALTERNATIVE 3 WITH OPTIONS 1-2

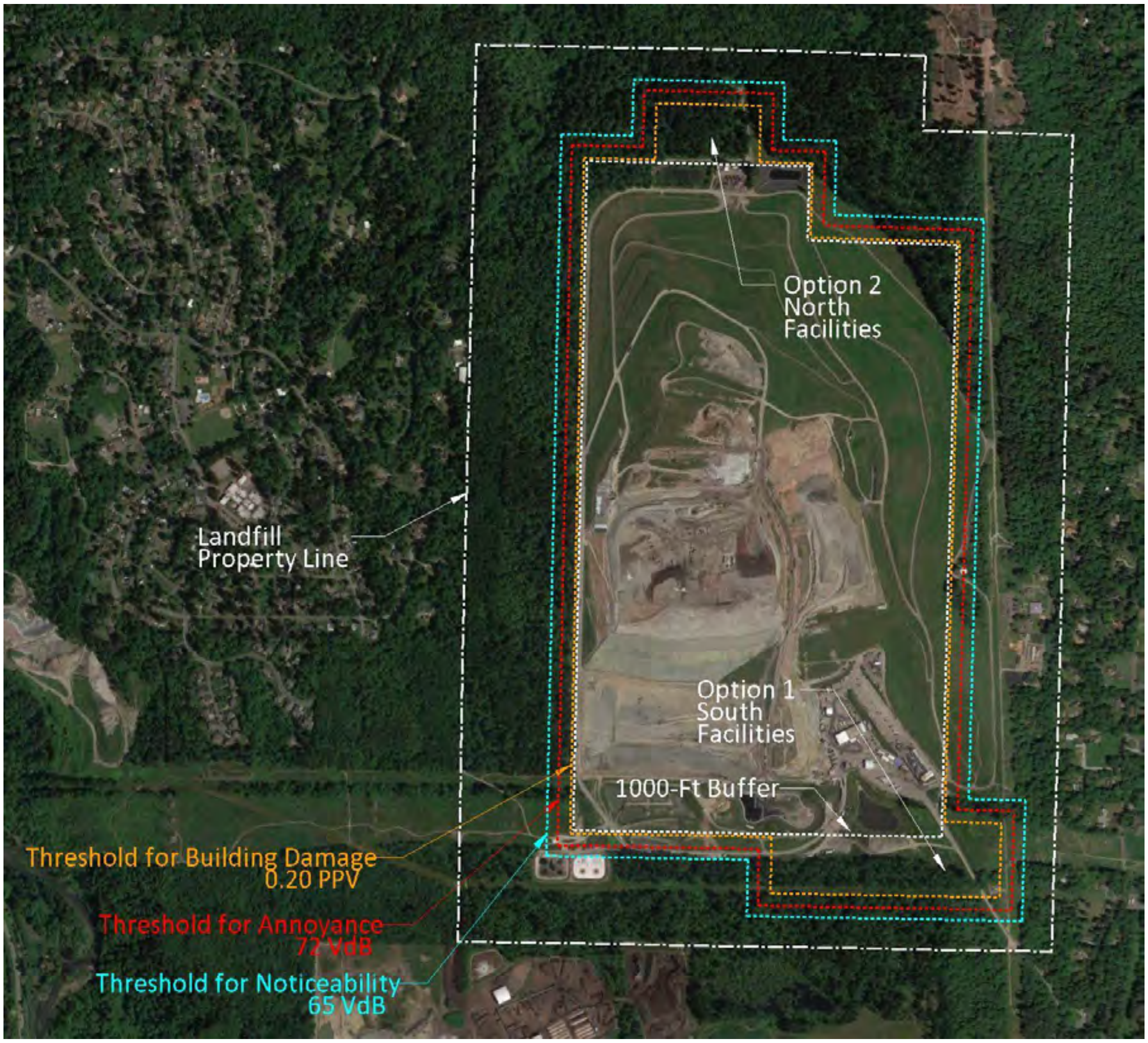
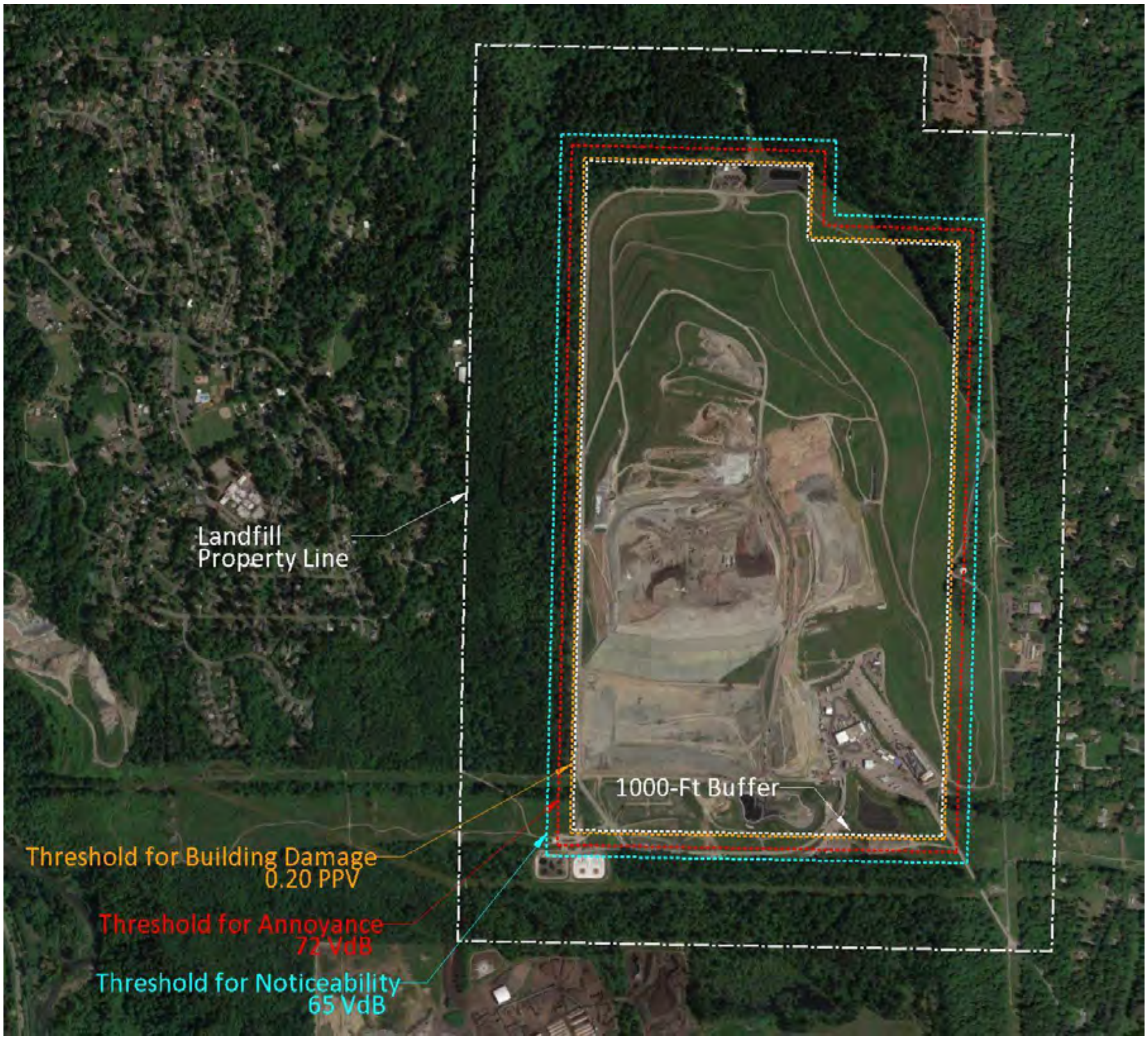


FIGURE 3.6: HEAVY EQUIPMENT VIBRATIONS - ALTERNATIVE 3 WITH OPTION 3



3.4.2 North Flare Station Vibration Levels

The 2014 *Noise and Vibration Study of Cedar Hills Regional Landfill North Flare Station* (Reference 2) describes the results of the 2013/2014 noise and vibration study performed for the CHRLF North Flare Station (NFS). The results of the study are still applicable since the same basic equipment is still in use. In that study, vibration levels were measured during operation of the NFS at various locations. The summary results of that vibration analysis are presented in the remainder of Section 3.4.2.

Vibration levels were measured at the locations shown in Figures 3.7 and 3.8. Vibration monitoring was accomplished by use of magnetically attaching accelerometers. At Positions V1 to V4, the accelerometers were mounted on metal plates that were adhesively attached to stakes driven about 18 inches into the ground. At perimeter locations, Positions V5 and V6, the accelerometer was mounted at the base of Department of Ecology well heads.

FIGURE 3.7: VIBRATION MONITORING POINTS (CLOSE-IN)

Source: Google and Reference 2

<u>FIGURE 3.8: VIBRATION MONITORING POINTS (PROPERTY LINE)</u>

Source: Google and Reference 2

<u>3.4.2.1 Comparison of Flare ON/OFF Conditions</u>

Measurements were taken at several locations using a 3-axis accelerometer with the flares ON (in a steady state condition) and OFF to determine how much ground vibration is due to flaring activities and whether the vibration level was significant enough to warrant mitigation. The accelerometer was oriented with one axis oriented vertically, one axis oriented towards the flares (radially), and the third axis was oriented perpendicular to the other two axes (transverse direction). So if an observer were oriented in a manner similar to the accelerometer, radial vibration motion would be the motion to-and-from the flares, the transverse motion would be the left-to-right motion, and the vertical motion would be up-and-down.

The measurements were taken at the positions shown in Figure 3.7 and Figure 3.8. The candlestick and the pumps/blowers/motors associated with the NFS were active for both the flare ON and OFF conditions.

A single flare was operational during the measurements at V1-V4 and three flares were on during the property line measurements at V5 and V6.

The results indicate that the vibration levels near the flare station with a single flare lit were well below the FTA criteria for human annoyance. With 3 flares lit (full capacity) the vibration levels would be a maximum of about 9.5 dB louder, but would still be well below the FTA criteria. At the property line locations, V5 and V6, there was no significant difference between the measured vibration levels with the three flares ON or OFF. The conclusion was that no further action was required with regards to vibration from steady state flare activity.

Steady State Vibration levels for each axis at the two closest vibration stations to the NFS, V1 and V2, are plotted in Figures 3.9 to 3.14. The measurements at V3 and V4 were generally similar but, due to the significantly increased distance from the flares, appear to be more influenced by the background vibration level than by vibration from the flares.

FIGURE 3.9: POSITION V1 – TRANSVERSE AXIS (27 FT.)

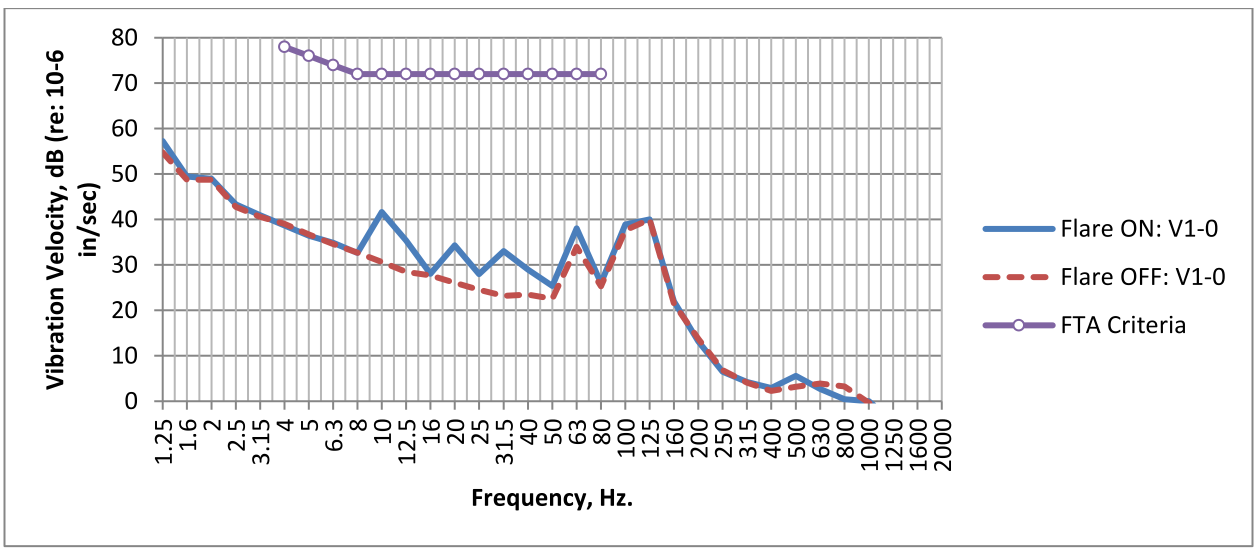


FIGURE 3.10: POSITION V1 – RADIAL AXIS (27 FT.)

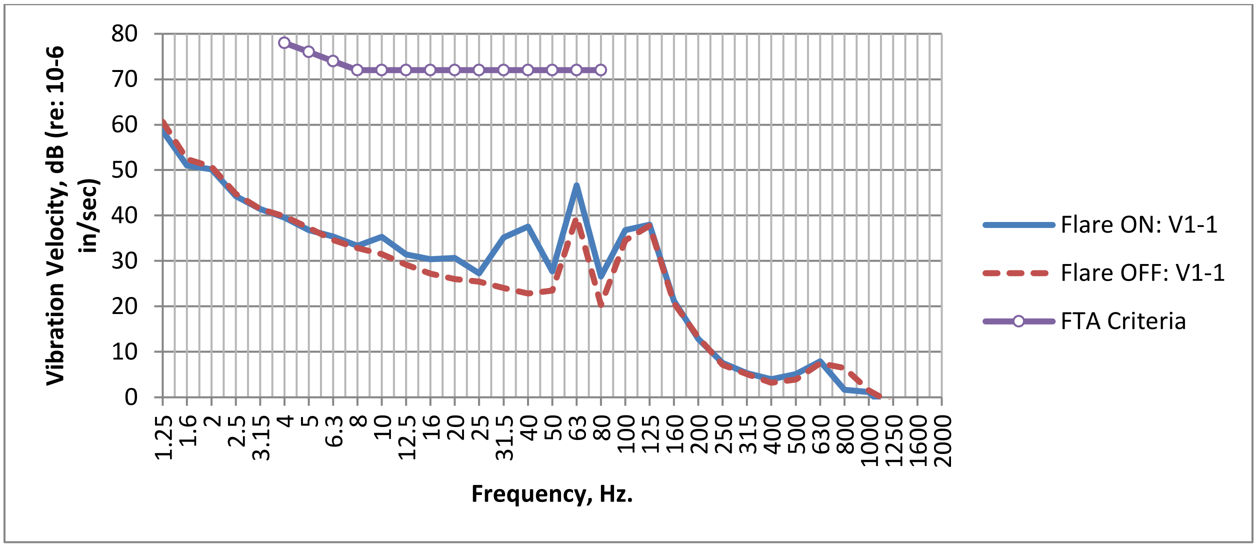


FIGURE 3.11: POSITION V1 – VERTICAL AXIS (27 FT.)

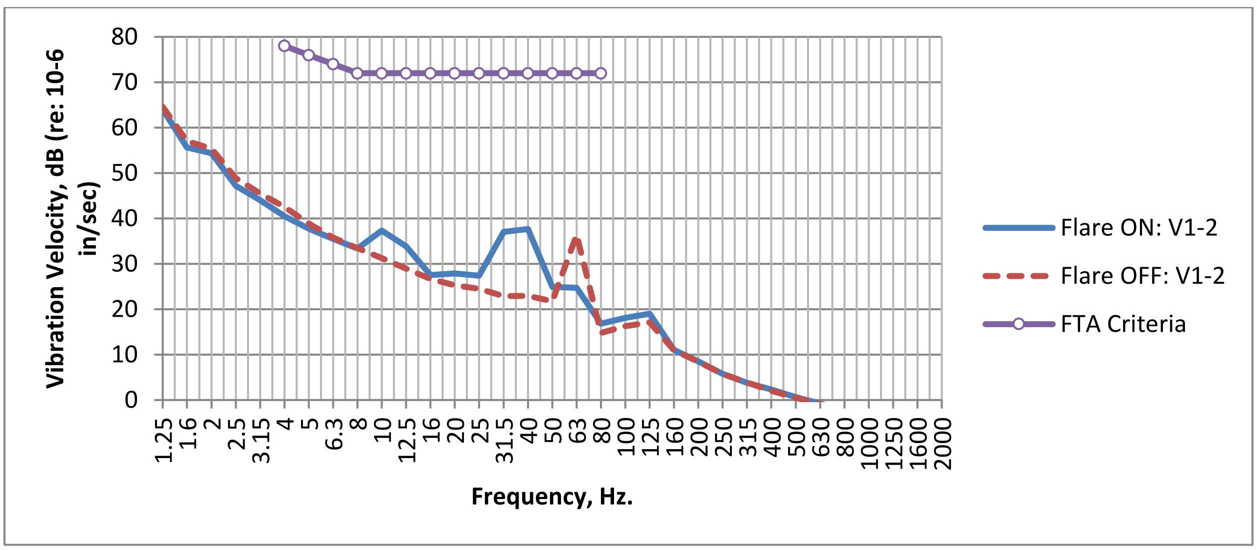


FIGURE 3.12: POSITION V2 – TRANSVERSE AXIS (111 FT.)

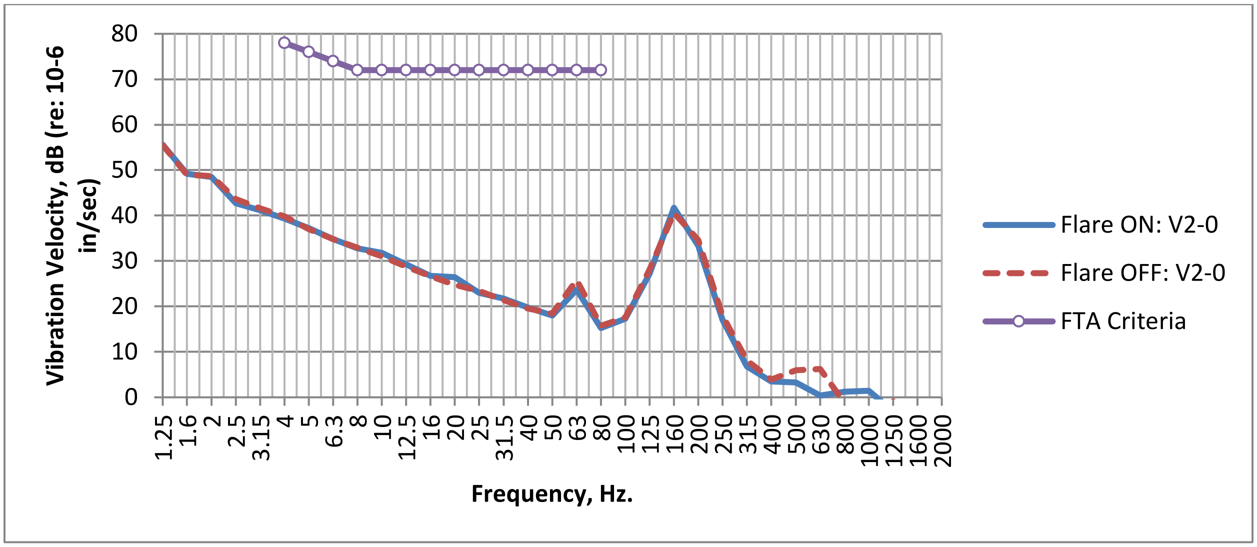


FIGURE 3.13: POSITION V2 – RADIAL AXIS (111 FT.)

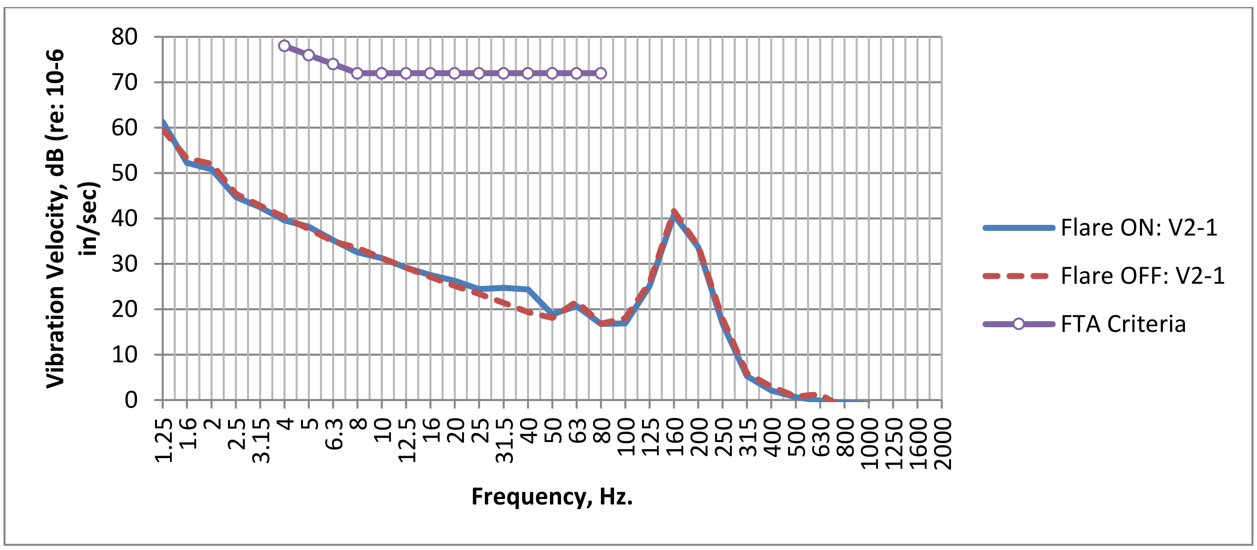
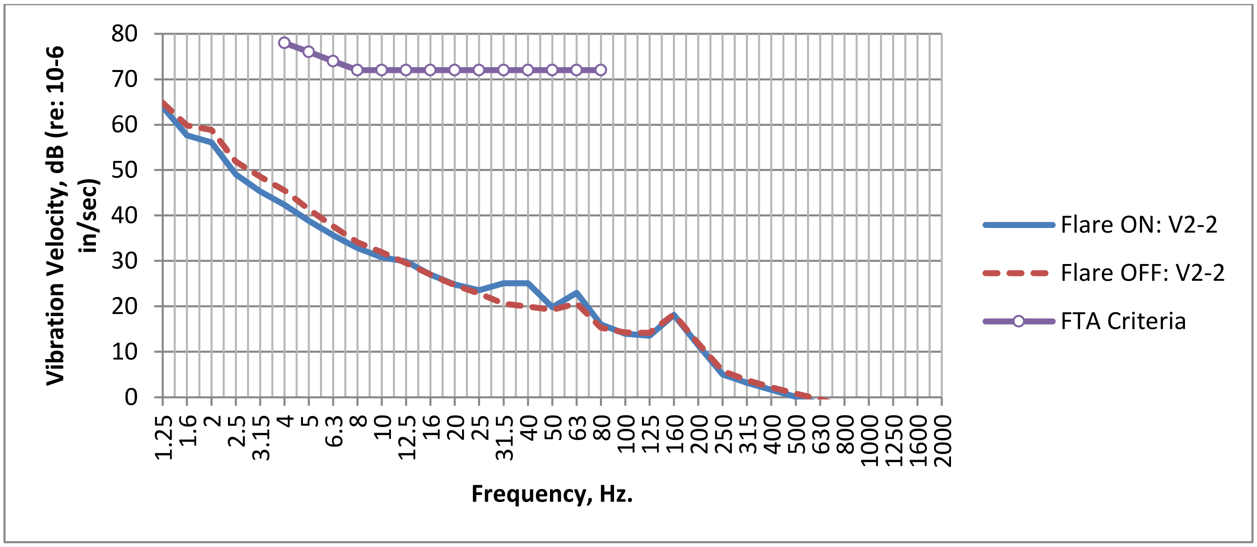


FIGURE 3.14: POSITION V2 – VERTICAL AXIS (111 FT.)



As seen in Figures 3.15 to 3.18, there is no evidence of operational impact from the flares at the east or west property line since the flare ON vibration levels are not significantly changed from the flare OFF condition. The vibration levels measured near the flares is considerably less than the FTA criteria for vibration.

The conclusion is that vibration from the flares at a distance of 75 feet is far less than what the FTA considers a threshold for human annoyance or where further study is warranted. Further, at the property lines the vibration level had diminished to the point that it was not distinguishable from the background level.

FIGURE 3.15: RADIAL VIBRATION AT POINT V6 (2000 FT.)

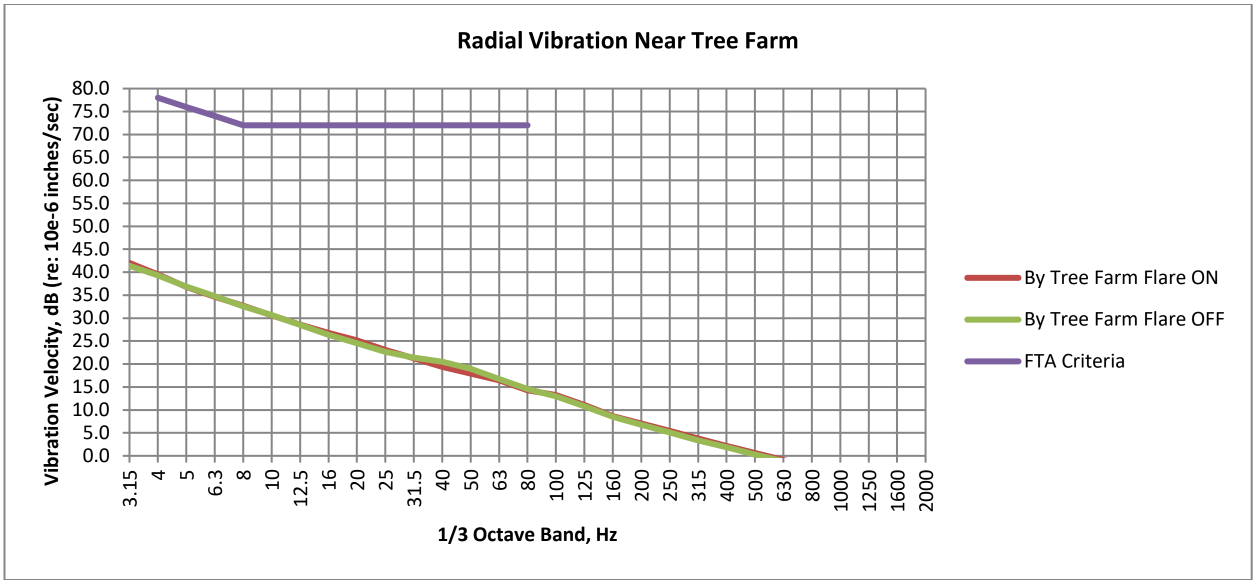


FIGURE 3.16: VERTICAL VIBRATION AT POINT V6 (2000 FT.)

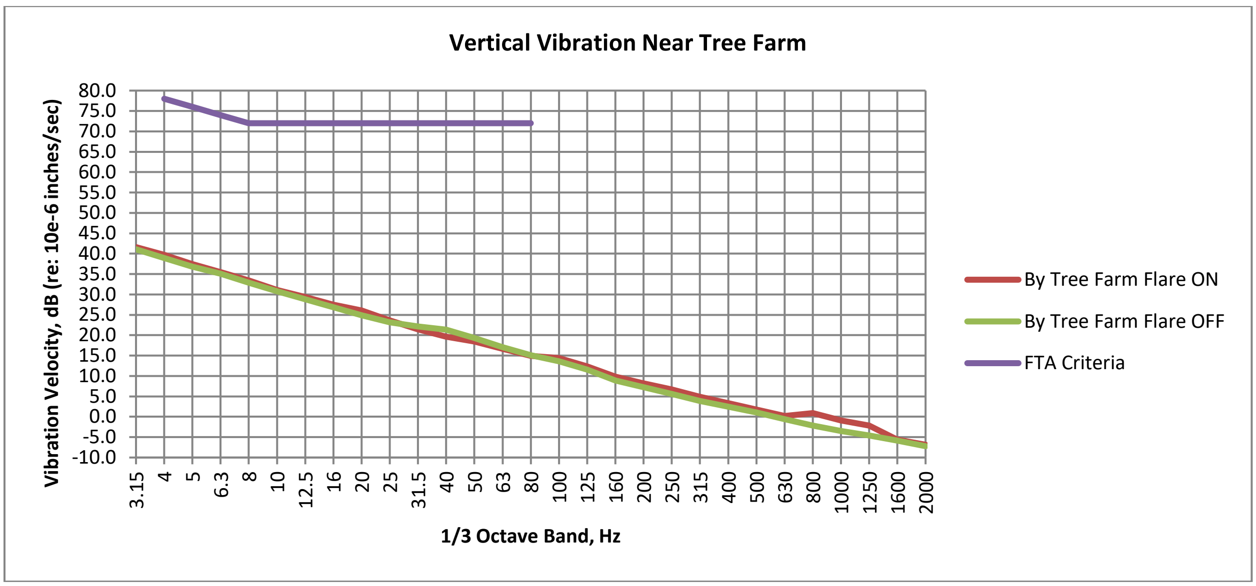


FIGURE 3.17: RADIAL VIBRATION AT POSITION V5 (2800 FT.)

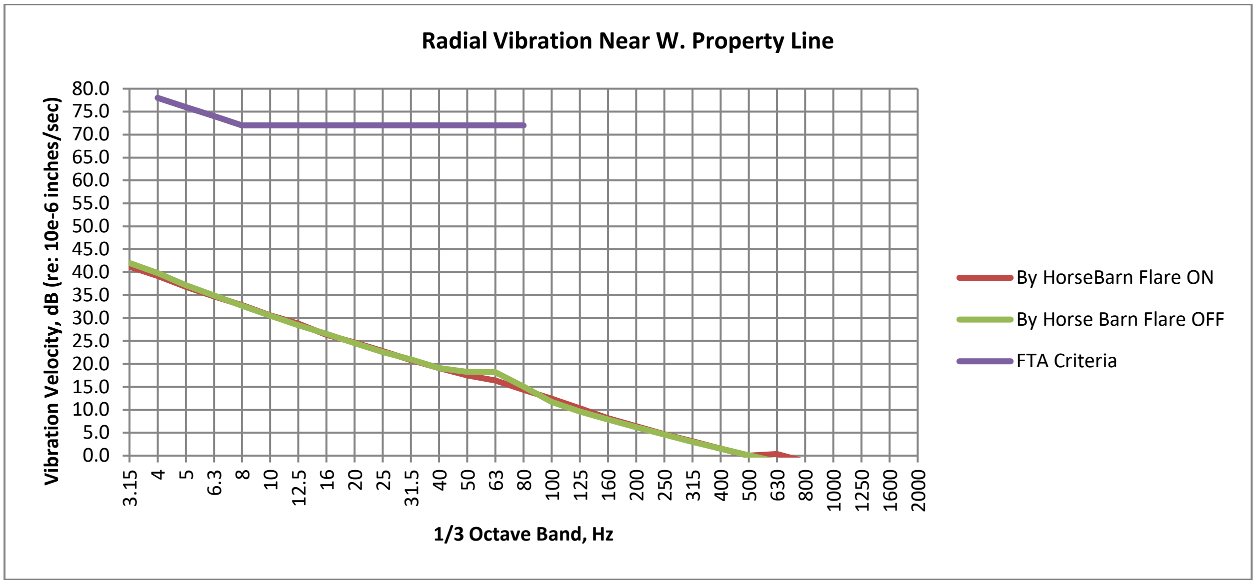
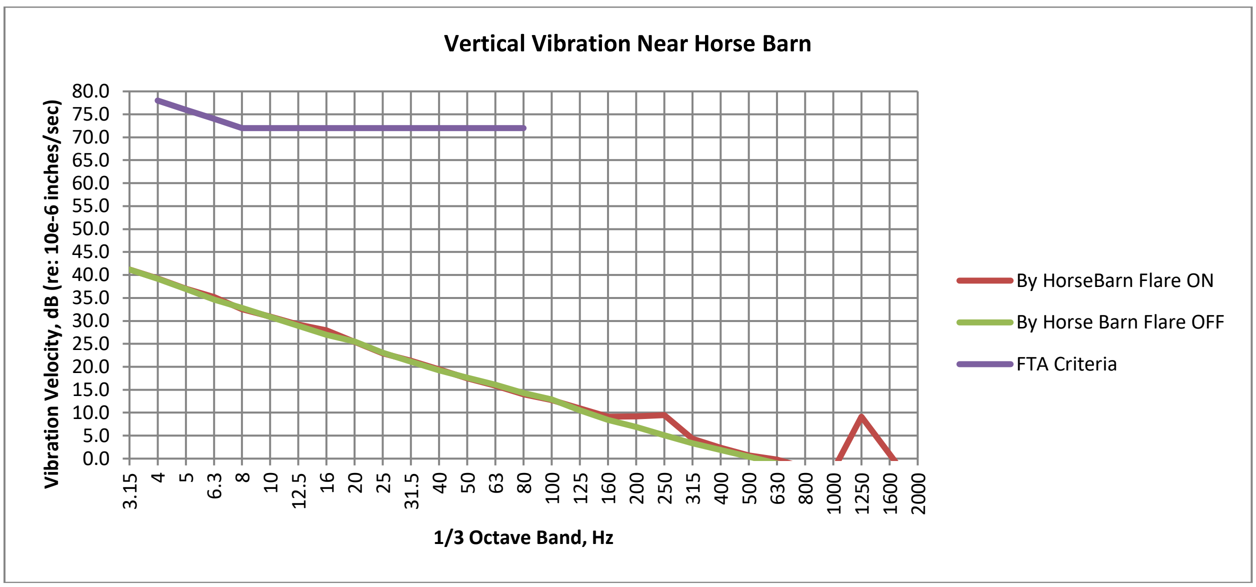


FIGURE 3.18: VERTICAL VIBRATION AT POSITION V5 (2800 FT.)[6]



3.4.2.2 Comparison of Non-Steady State NFS Operations

Vibration measurements were taken to compare the vibration levels during flare startup with the steady state vibration level. Measurements were taken at Positions V1-V4 as shown in Figure 3.7. The procedure was to switch from one operating flare to another and to compare vibration levels before

[6] Note that the vertical vibration in the 1250 Hz band was not steady and was believed to be caused by hammering/construction that was occurring in the vicinity of the horse barn during the measurement period.

ignition, during the ignition, and after the ignition. The blowers, candlestick, and other typical NFS sources were present in addition to the flares.

The vibration levels observed during operation of the flares was fairly constant with no noticeable change when alternating from one flare to the other.

Figures 3.19 - 3.22 show the vertical third octave vibration spectra at V1 (linearly averaged) for three conditions: the minute leading up to the time when the first flare was shut off, the 30 seconds surrounding the time that the flares were changed, and the minute after the second flare was started. Odd numbered runs started with flare #5 ON which was then switched to #4. The opposite was true for even numbered runs. There was no significant difference when switching between #5 and #4. The data when switching from #4 to #5 is shown since position V1 was closer to the #5 Flare.

Examination of Figures 3.19 - 3.22 leads to the conclusion that there is no vastly different vibration characteristic during normal flare startup. Further, the levels that are measured, either during ignition or during steady state operation, are well below the FTA threshold.

FIGURE 3.19: RUN #2 THIRD OCTAVE VIBRATION LEVELS (POSITION V1 27 FT.)

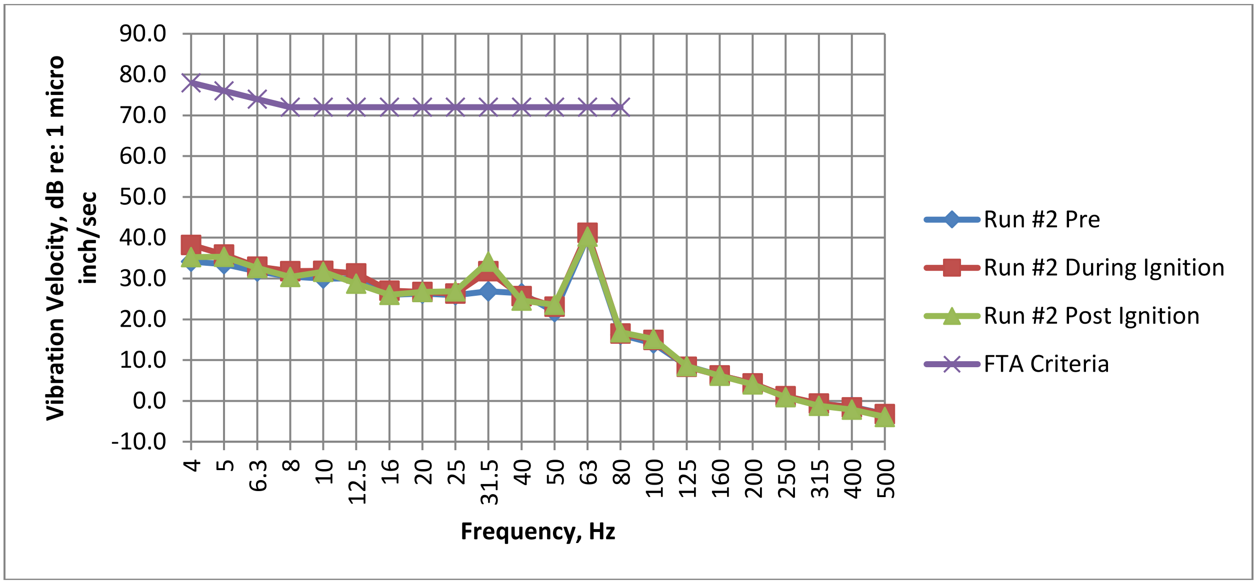


FIGURE 3.20: RUN #3 THIRD OCTAVE VIBRATION LEVELS (POSITION V1 27 FT.)

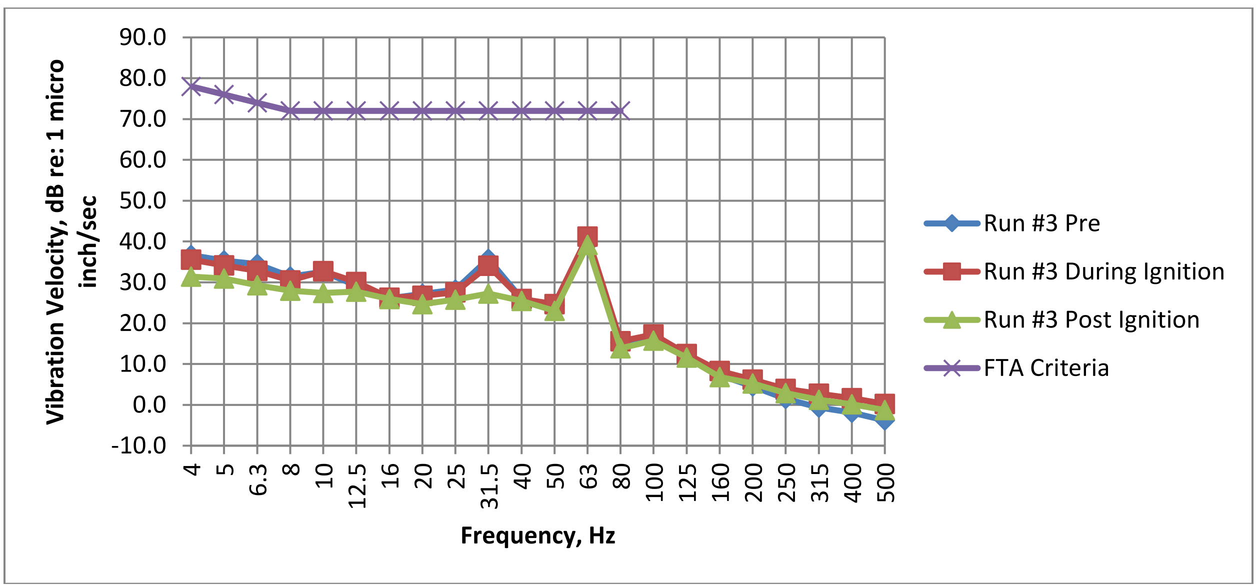


FIGURE 3.21: RUN #4 THIRD OCTAVE VIBRATION LEVELS (POSITION V1 27 FT.)

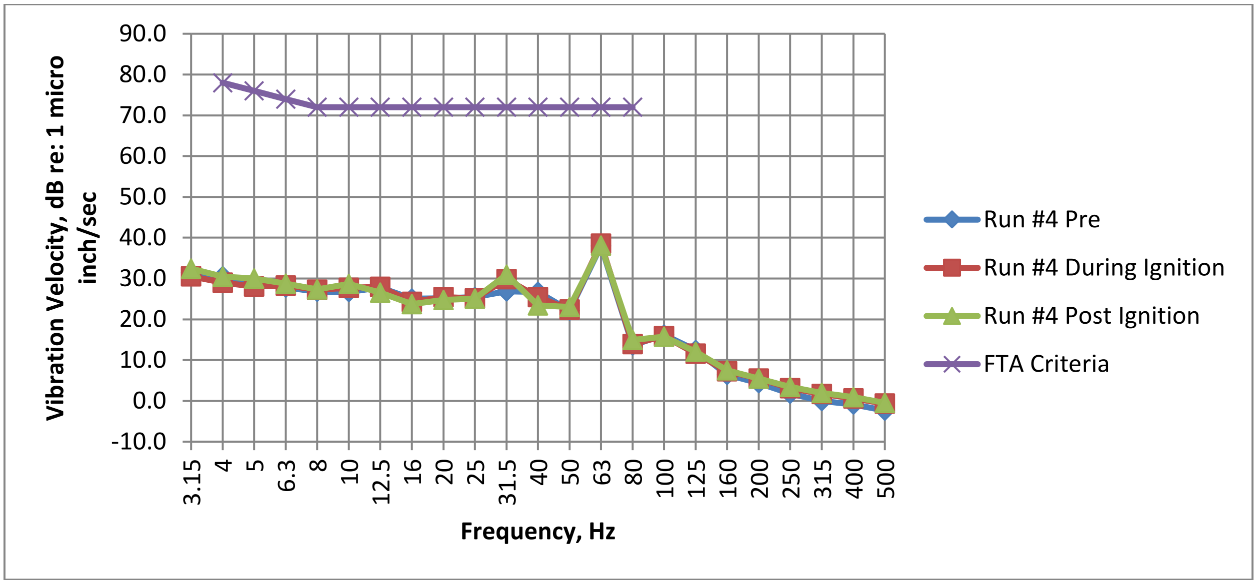


FIGURE 3.22: RUN #6 THIRD OCTAVE VIBRATION LEVELS (POSITION V1 27 FT.)

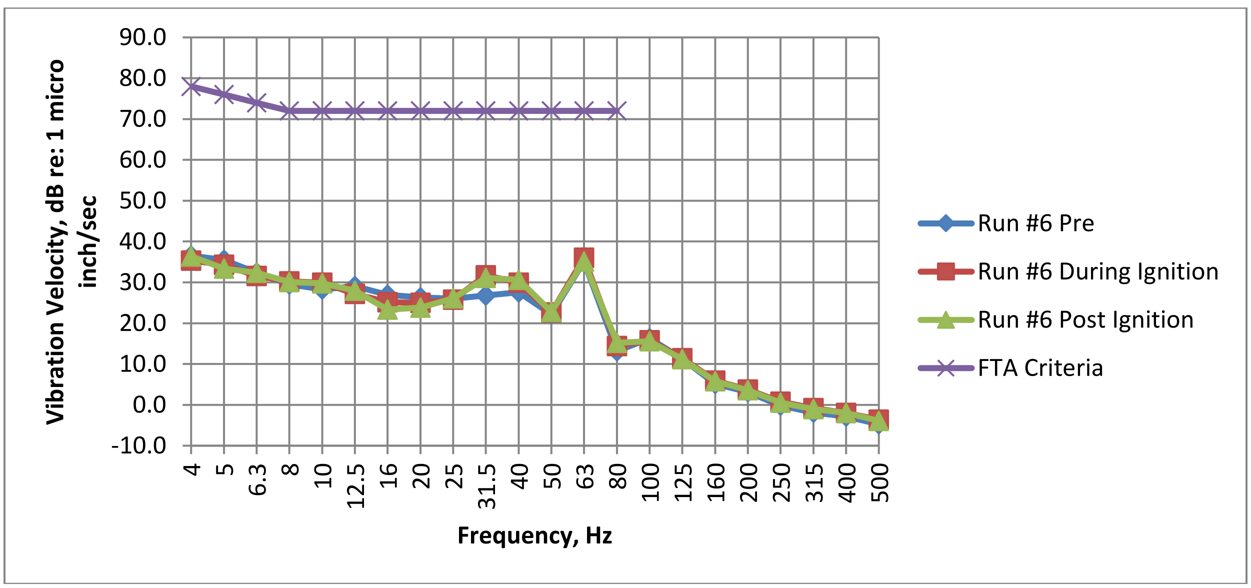
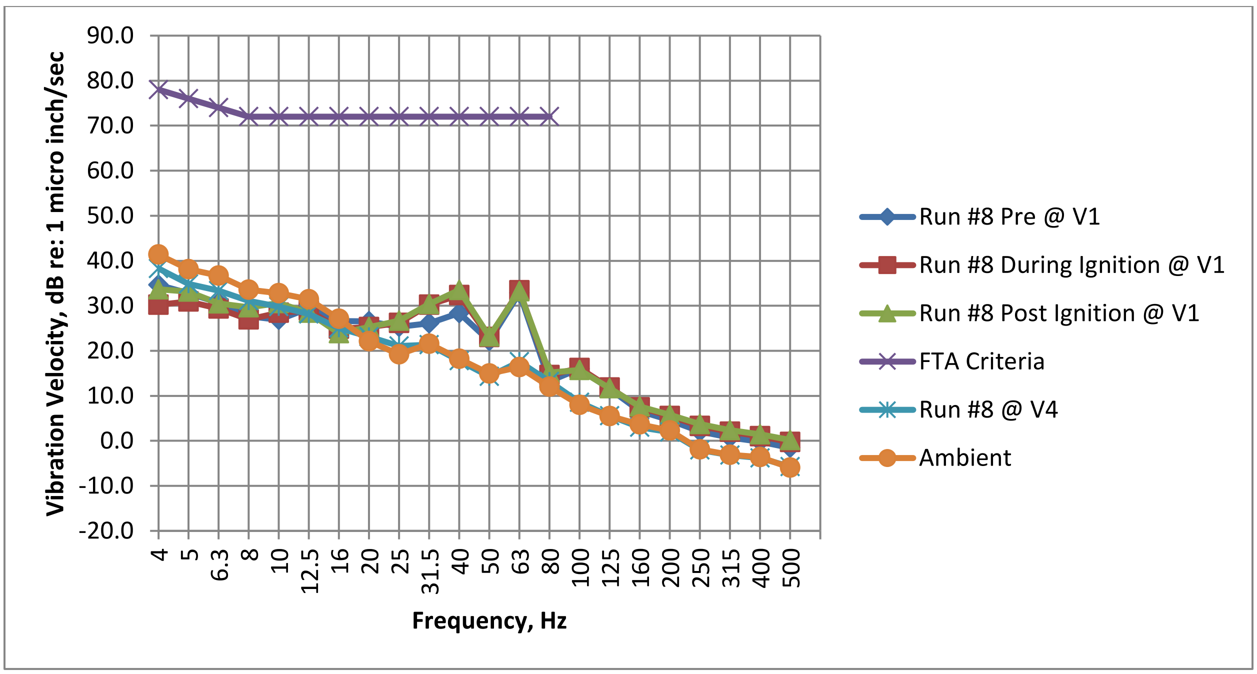


Figure 3.23 compares the spectra measured at V1 with the spectra measured at V4 (213 yards away) and the spectra with the flare OFF. The conclusions that we can draw from the figure are:

- The flare's strongest vibration is created in the 31.5 and 40 Hz bands. These are the only bands that change significantly when the operable flare is changed between #4 and #5.
- The rather strong tone at 63 Hz appears to be caused by something other than the flares themselves as it does not vary in intensity when switching from #4 to #5, and vice versa.
- There is no significant difference between the measured level with the flare ON and the flare OFF at a distance of 213 yards. This implies that the flare vibration is minimal at this point and the measured vibration level is primarily due to other sources.
- Even if all observed vibration levels at V1 (9 yards from flares) were due to the flare operation, it is still far below FTA standards. If 4 flares were operational, the projected levels could be as much as 12 dBV higher[7], but still well below the FTA threshold.

FIGURE 3.23: RUN #8 THIRD OCTAVE VIBRATION (POSITION V1 (27 FT.)& V4 (639 FT.))



[7] It is highly unlikely that the full 12 VdB increase would be observed since all vibration produced by the flares would have to be in-phase.

3.4.2.3 NFS Vibration Conclusions

The NFS vibration study demonstrated that:

- Near the Flares within 75-110 feet, there is some vibration due to their operation. However, it is well below any impact criteria. Use of all flares continuously would still produce Lv levels well below any impact threshold.
- Measured vibrations levels at the property line with all flares operating were not distinguishable from the background vibration levels.
- Vibration levels during normal startup of the flares was performed and no significant difference in steady state versus transitional vibration levels was found.

Because the vibrations caused by the flares are less than the vibrations due to the heavy equipment discussed in 3.4.1 and since the North Flare Station is inside the landfill buffer line, the vibration contour limits shown in Figures 3.3 to 3.6 are valid with or without the activity at the NFS.

These findings demonstrate that there would be no vibration impact on the community due to continued operation of the North Flare Station under Action Alternatives 1-3 (with Options 1-3). Further, Action Alternatives 1-3 would not increase vibration levels relative to the No Action Alternative by any observable amount. Thus, there are no significant unavoidable impacts.

3.4.3 Impact Conclusions

The analysis demonstrates that projected vibration levels associated with the Action Alternatives and No Action Alternative, including vibrations caused by heavy equipment operation and the North Flare Station operation are much less than the threshold for human annoyance, human perception, and building damage. Thus, none of the Alternatives and Options have projected vibration levels that would constitute a significant impact relative to the No Action Alternative. No vibration mitigation is necessary.